Computational social science

Agent-based models & emergence

or

"how to build and play with your own artificial societies"

Course structure

Period IV

Week	Lecture	Exer. dl	Ext. dl	Topic
1	~~Feb 27~~	~~Mar 3~~	~~Mar 15~~	~~Introduction to CSS~~
2	~~Mar 6~~	~~Mar 10~~	~~Mar 22~~	~~Artificial societies & agent-based models~~
3	~~Mar 13~~	~~Mar 17~~	~~Mar 29~~	~~Data & digital traces~~
4	~~Mar 20~~	~~Mar 24~~	~~Apr 5~~	~~Counting things & analysing text~~
5	~~Mar 27~~	~~Mar 31~~	~~Apr 12~~	~~Social networks: structure~~
6	~~Apr 3~~	*	-	~~Introduction to the project~~

***Project deadline: May 26**
Project peer review: June 2

Period V

Week	Lecture	Exercise dl	Ext. dl	Topic
7	Apr 24	May 5	May 10	Ethics, privacy, legal
-	-	-	-	~~WAPPU~~
8	May 8	May 12**	May 24	Agent-based models & emergence
9	May 15	May 19***	May 31	Social networks: dynamics
10	May 22	May 26***	June 7	Experiments & interventions at scale
11	May 29	-	-	Computing for social good

****Bonus round**
*****Only lecture questions**

Can we model social systems?

Why to build an agent-based model?

Flexible research questions: how does the behaviour of individual people/companies/countries/etc affect some society-wide phenomena?

Stylistic models

Show how some mechanism(s) lead to emergent phenomena

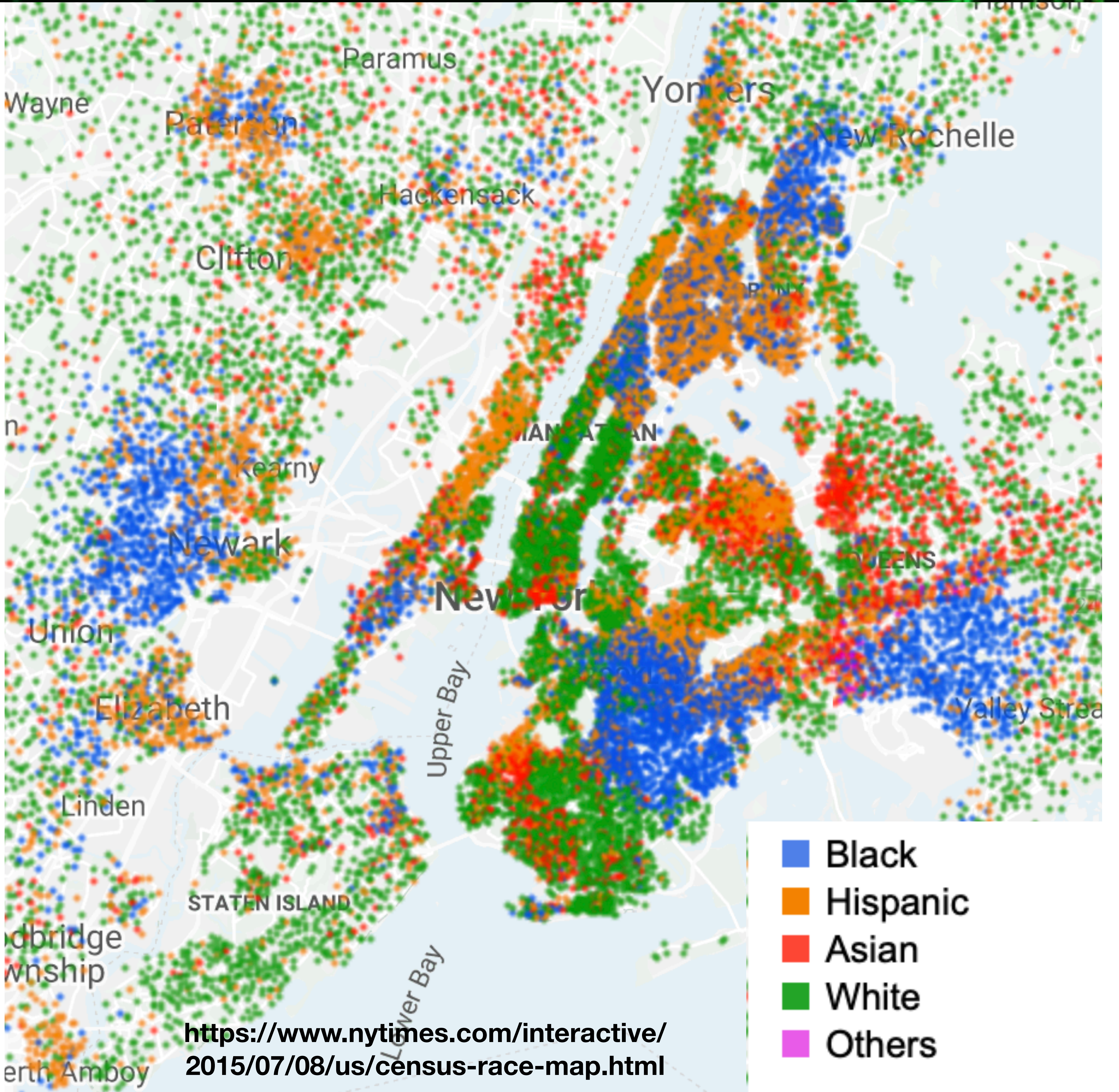
Microsimulations

Try to model reality as accurately as possible, fitting a model to data.

How does individual behavior lead to societal consequences?

Example: Segregation

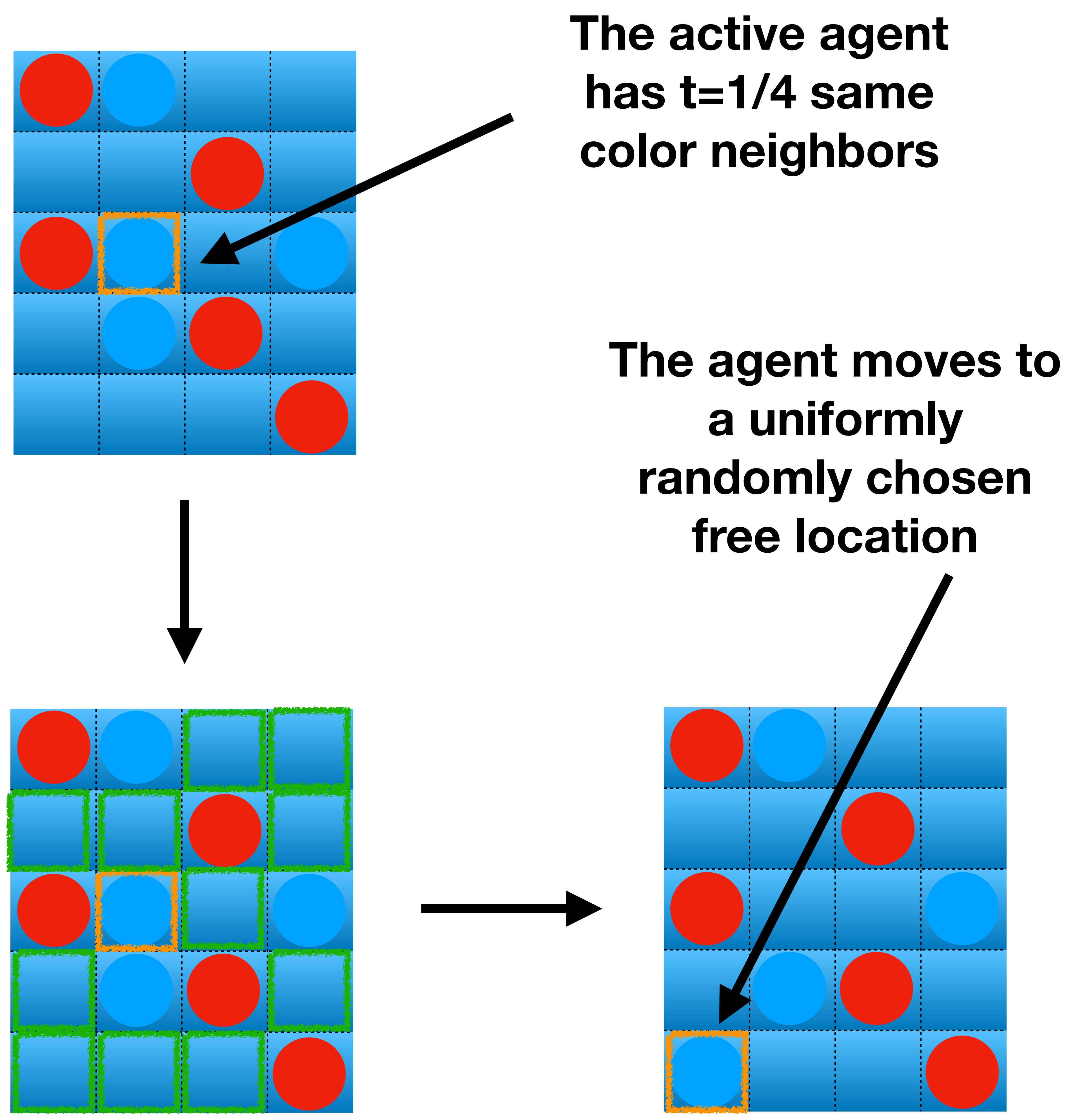
- Why is there segregation: racially/ economically/culturally homogenous neighbourhoods in cities?
- What are the mechanisms producing these?
    - Does it require organisation?
    - Do people only choose to live next to similar people?
    - Could small amount of preference towards similar people be an explanation?



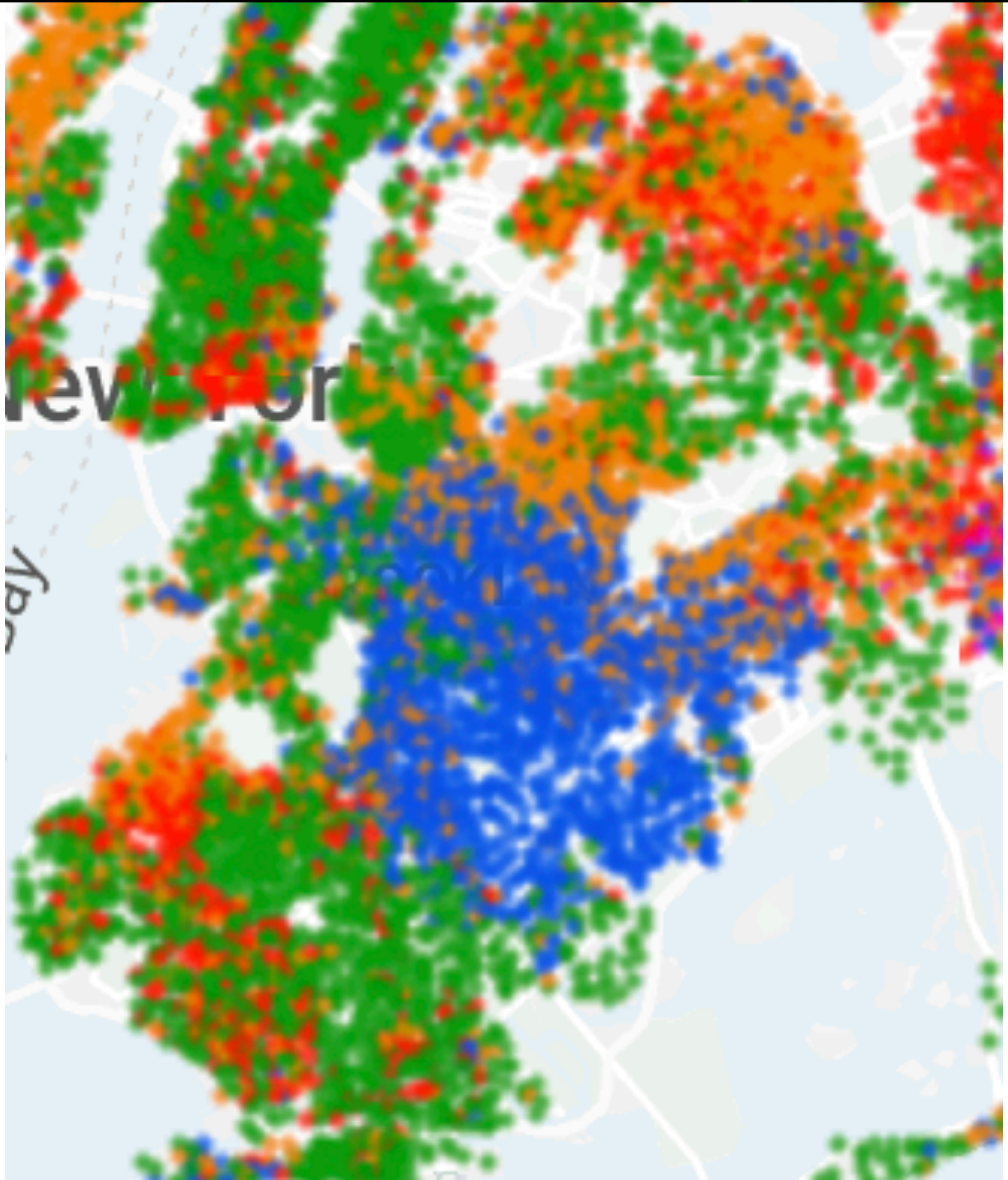
https://www.nytimes.com/interactive/2015/07/08/us/census-race-map.html

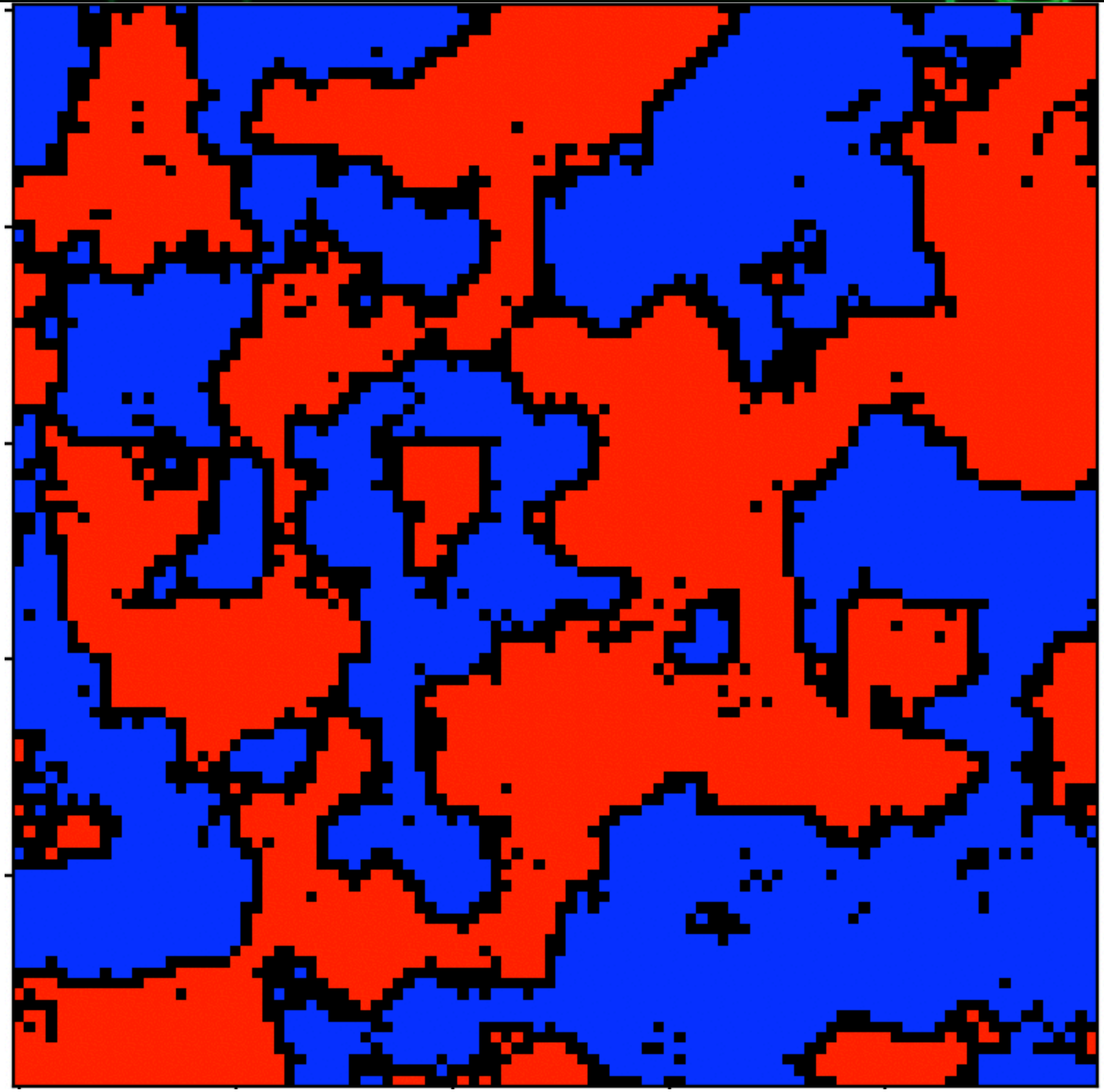
Agents: Schelling model

- *Threshold T*: how much same type of agents it needs in its neighbourhood
- Agent inspects its neighbourhood: what is the fraction, t, of same type agents?
- **If t < T**: the agent moves out
- **If t > T**: the agent is satisfied with its position



Results of the Schelling model

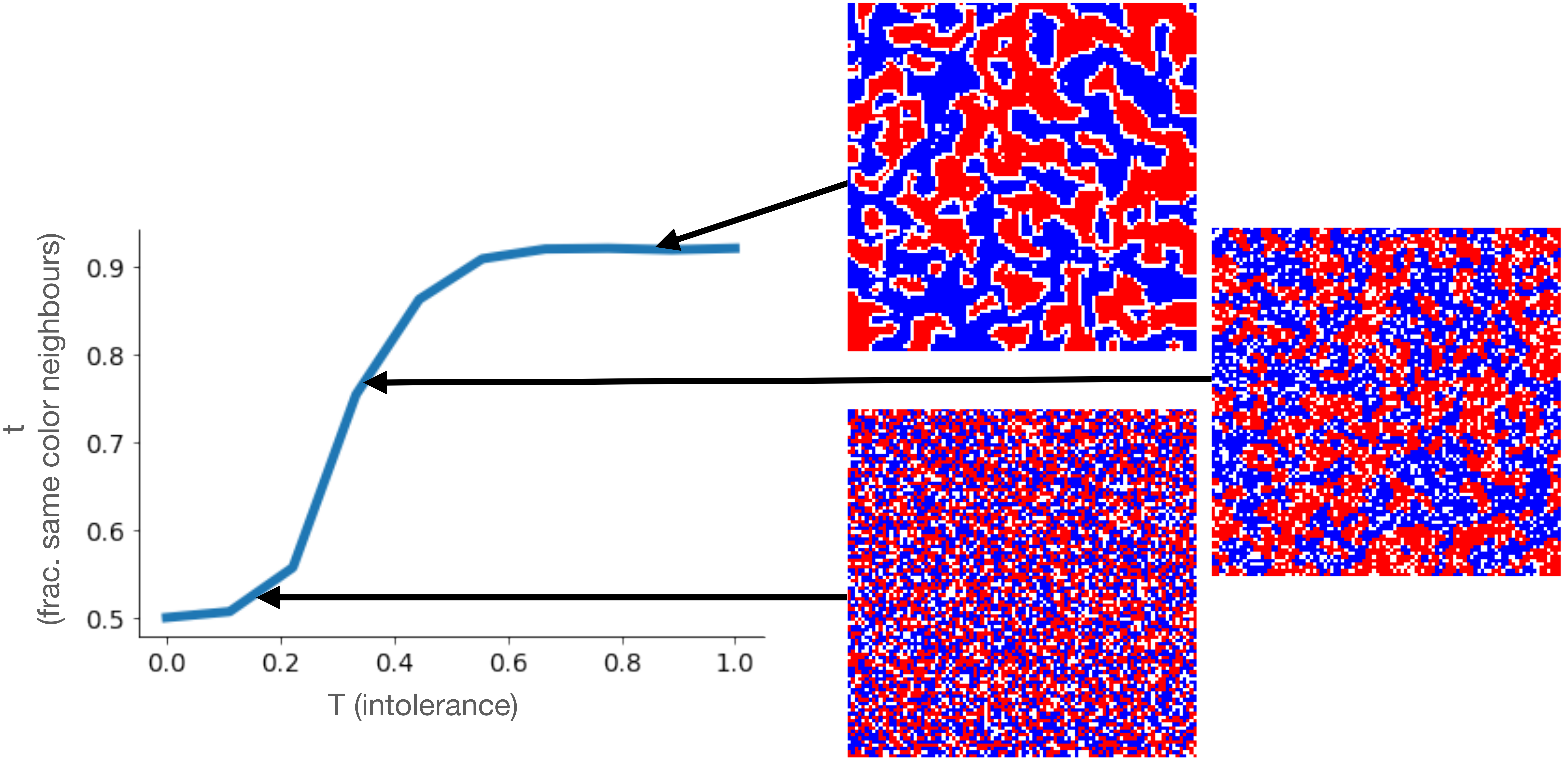




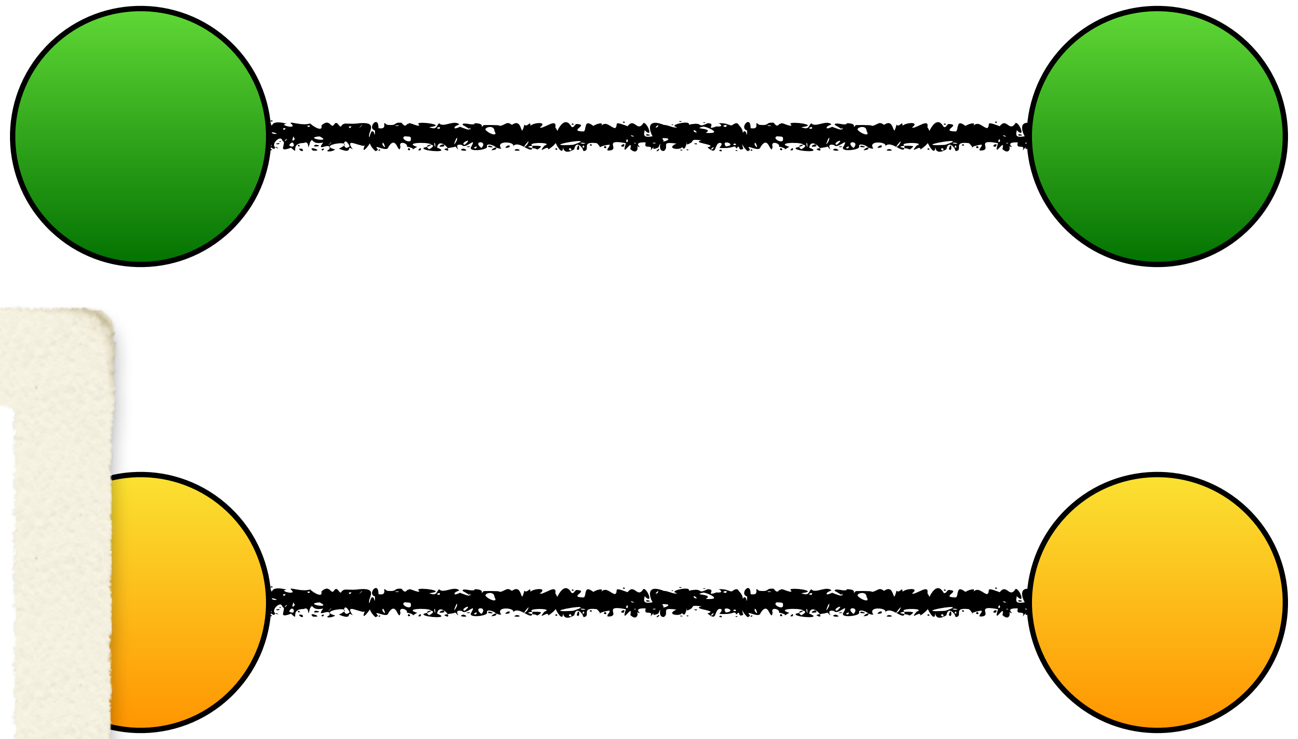
Schelling model, conclusions

1. Segregation can be an emergent phenomenon, no coordination required
2. Only a small preference towards similar neighbors leads to wide segregation
3. Effect is highly non-linear: small changes in preferences can lead to massive overall changes

Results of the Schelling model



Homophily



- Similar people tend to be connected to each other
- “Birds of the feather flock
- Observed in most social r
- Mechanism: choice homophily → lecture 9

Schelling model

Microscopic mechanism: *Homophiy* = tunable intolerance to different types of households
Macroscopic phenomenon: Only 1/3 of max intolerance needed to explain segregation

M McPherson, L Smith-Lovin, JM Cook "Birds of a Feather: Homophily in Social Networks”, Annual Review of Sociology Vol. 27:415-444 (2001)

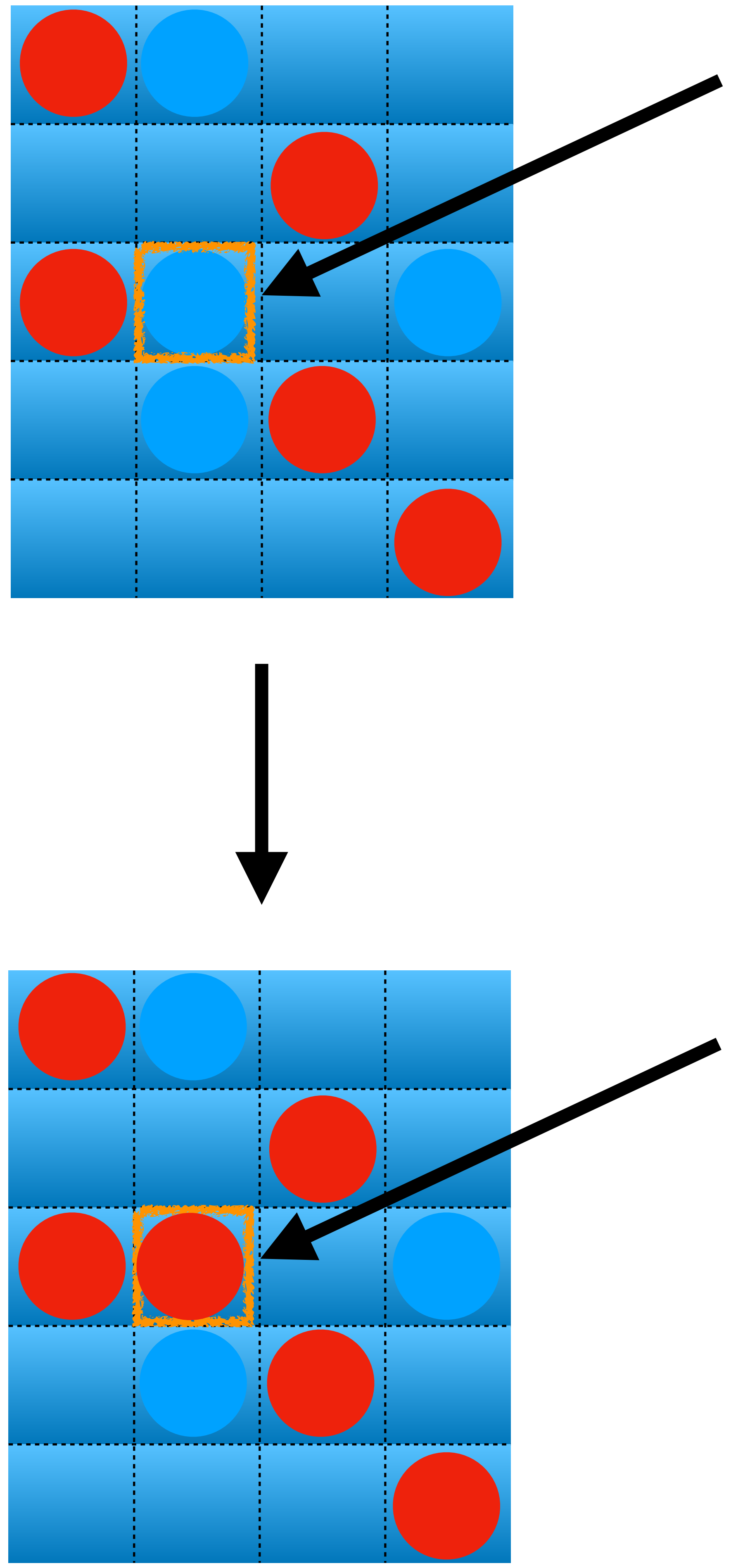
What other social mechanisms are there? What do they lead to?

Influence

- Social mechanism: people change their opinions/behavior they are interacting with
- Models for adaption/spreading: SI, SIR, threshold models, …
- Models for competing behavior/opinions: voter models, Sznajd model, majority rule model, …

A model for opinion dynamics

- Agent wants to change its opinion, but is influenced by its neighbors
- Agent inspects its neighbourhood:
  - s = number of same opinions
  - d = number of different opinions
- **If s-d ≤ 0**: the agent changes opinion
- **If s-d > 0**: the agent changes its opinion with probability $p^{(s-d)}$, where p is probability of one neighbour failing to convince them to keep the opinion

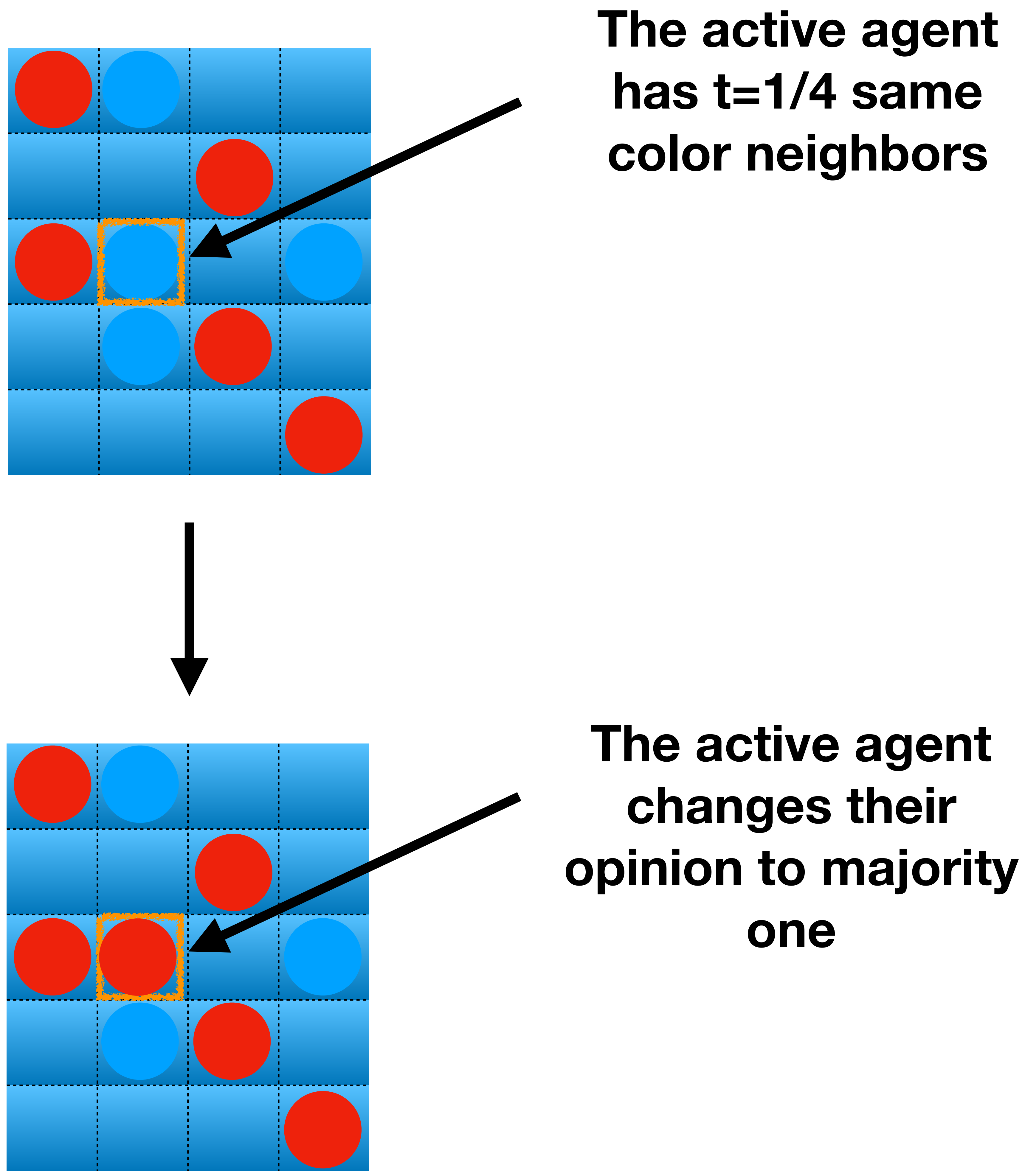


The active agent has t=1/4 same color neighbors

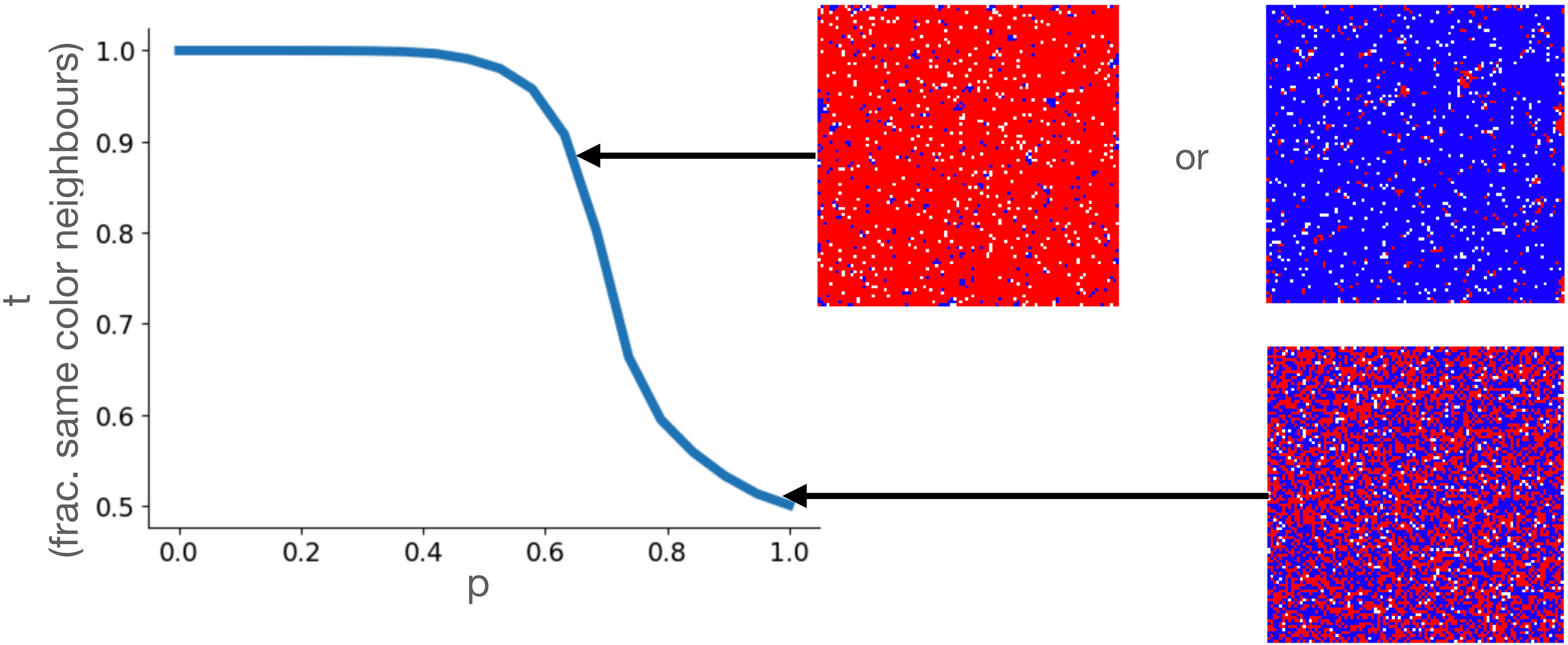
The active agent changes their opinion to majority one

A model for opinion dynamics

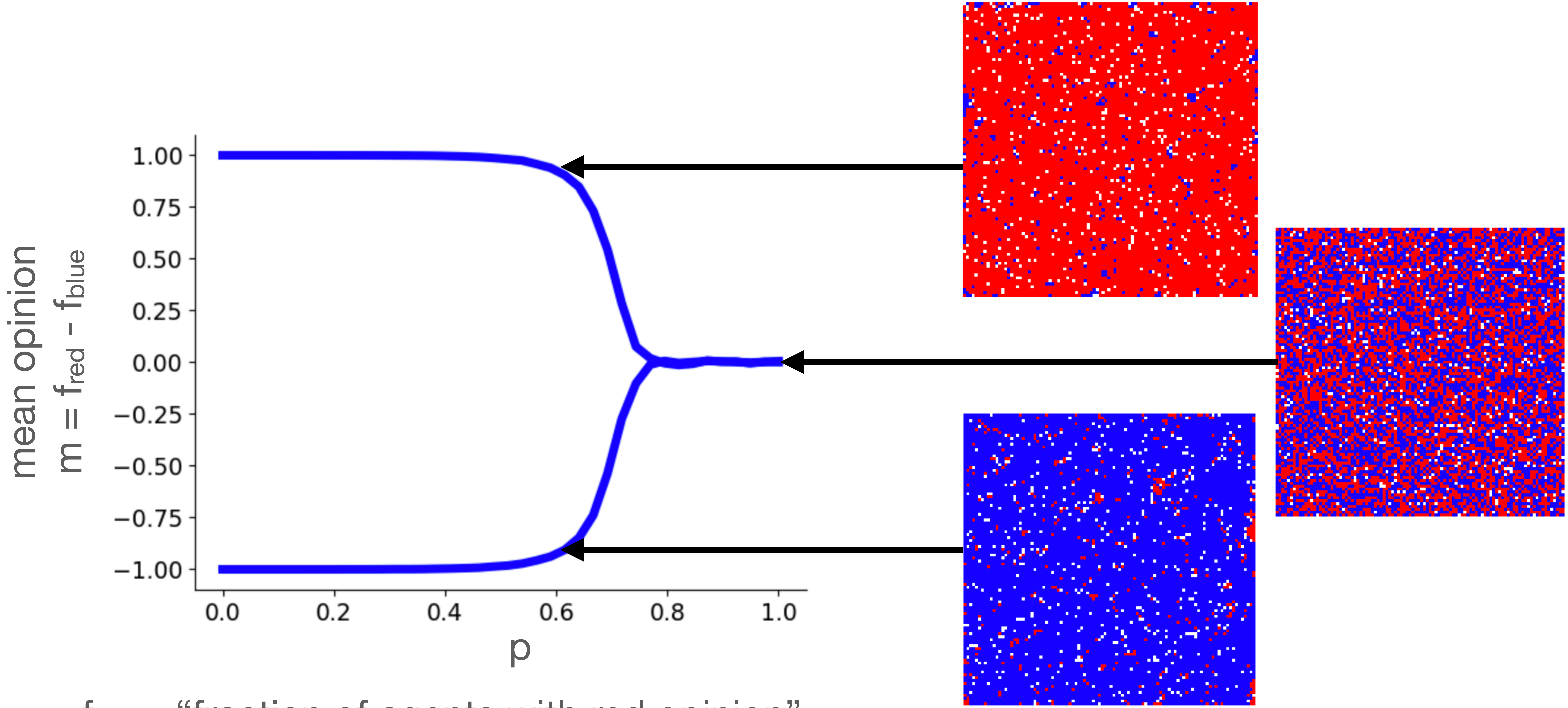
- Two main outcomes:
  - p is small: everyone ends up in the same opinion
  - p is large: the opinions remain more or less random
- Starting from random initialization either opinion could win
- Transition from one outcome to the other very rapid in terms of p



A model for opinion dynamics



A model for opinion dynamics



f_{red} = “fraction of agents with red opinion”

A model for opinion dynamics

- Two possible outcomes:
  - p is small: everyone ends
    same opinion
  - p is large: the opinions re
    less random
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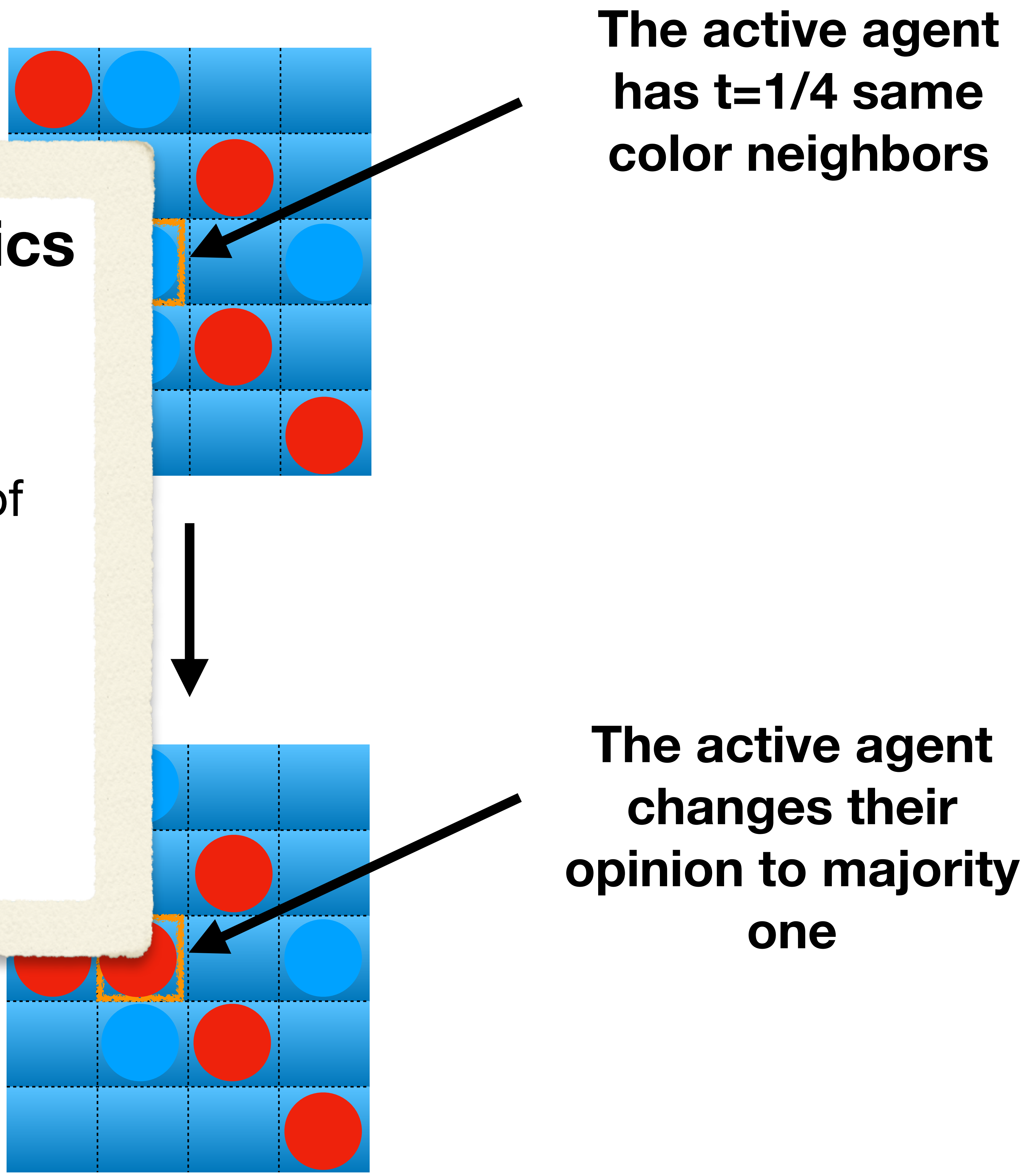
Simple opinion dynamics

Microscopic mechanism:
Influence = agents change opinions if enough neighbors of opposing opinion
Macroscopic phenomenon:
Either random opinions or everyone of same opinion depending on the changing tendency



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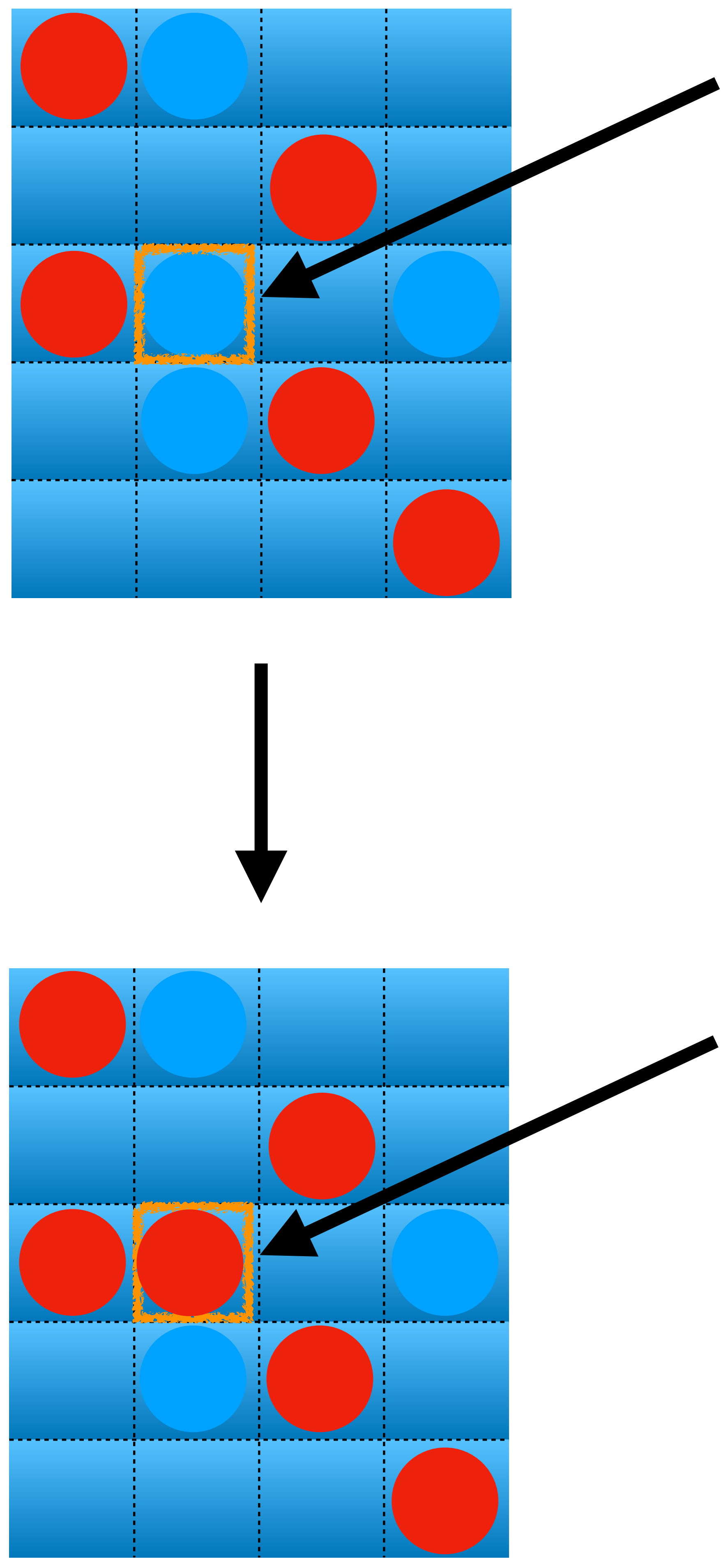
Schelling model

Microscopic mechanism:
Homophiy = tunable intolerance to different types of households
Macroscopic phenomenon: Only 1/3 of max intolerance needed to explain segregation

External influence & opinion dynamics

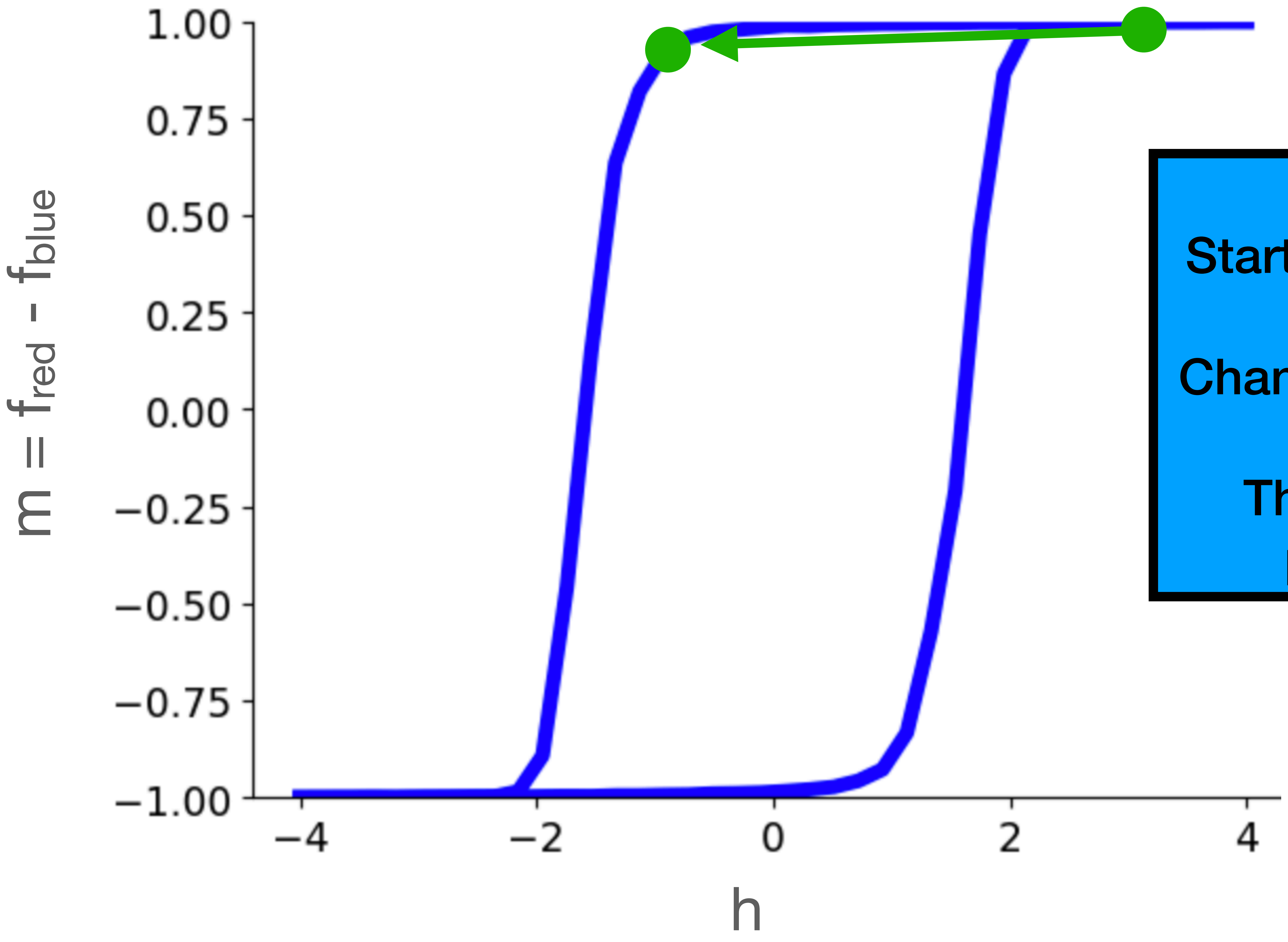
- Agent wants to change its opinion, but is influenced by its neighbors
- Agent inspects its neighbourhood:
  - s = number of same opinions
  - d = number of different opinions
  - h = external influence (positive if agent is red, negative if blue; if h is negative, then opposite)
- **If $s-d+h \leq 0$**: the agent changes opinion
- **If $s-d+h > 0$**: the agent changes its opinion with probability $p^{(s-d+h)}$, where p is probability of one neighbour failing to convince them to keep the opinion



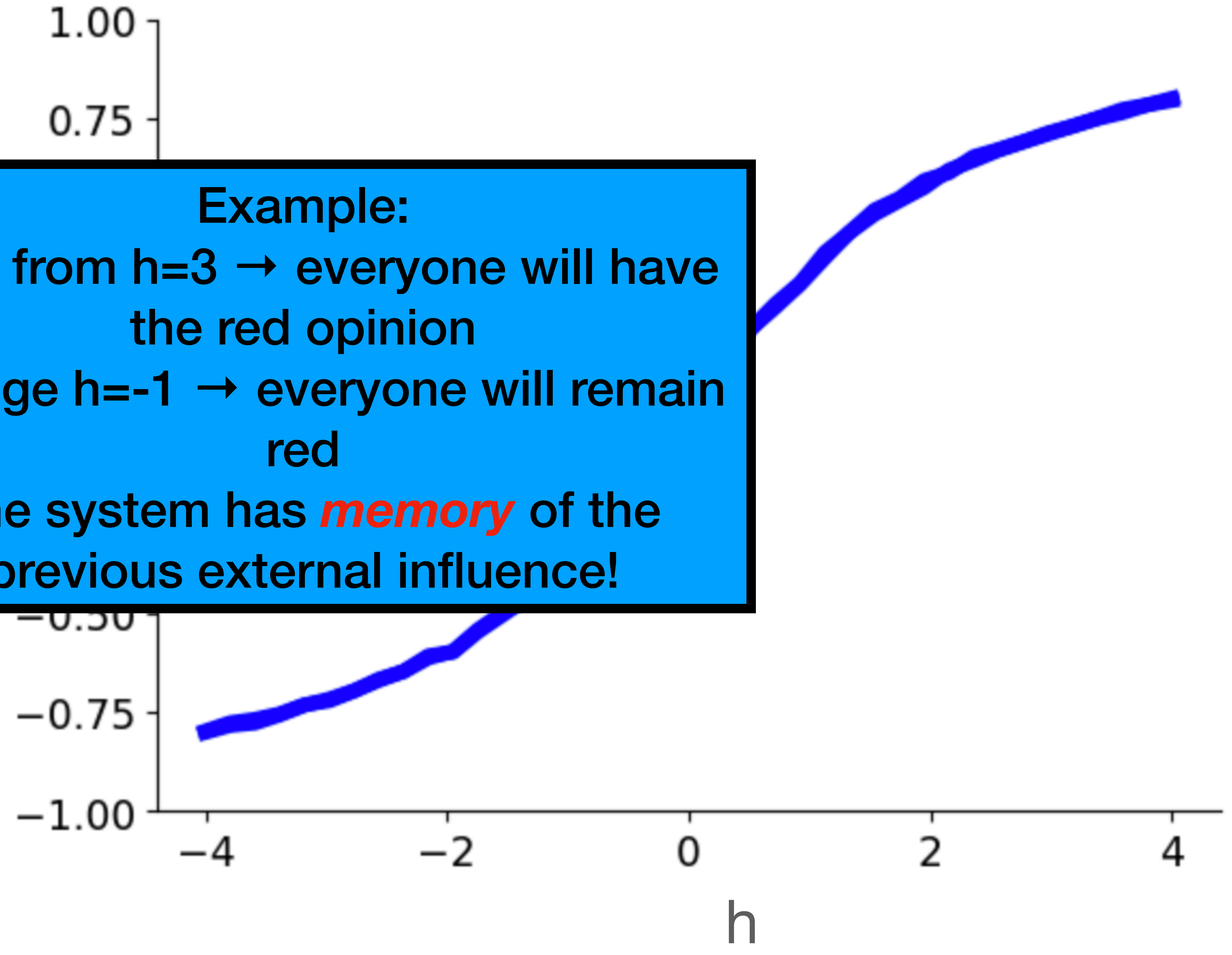
External influence & opinion dynamics

External influence & opinion dynamics

p = 0.5
(ordered phase when h = 0)



p = 0.8
(disordered phase when h = 0)



Example:
Start from h=3 → everyone will have the red opinion
Change h=-1 → everyone will remain red
The system has *memory* of the previous external influence!

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Opinion dynamics & external influence

Microscopic mechanism:
Local influence + *external influence*
Macroscopic phenomenon:
Small external influence has large effects, persistent effects even after external influence is removed

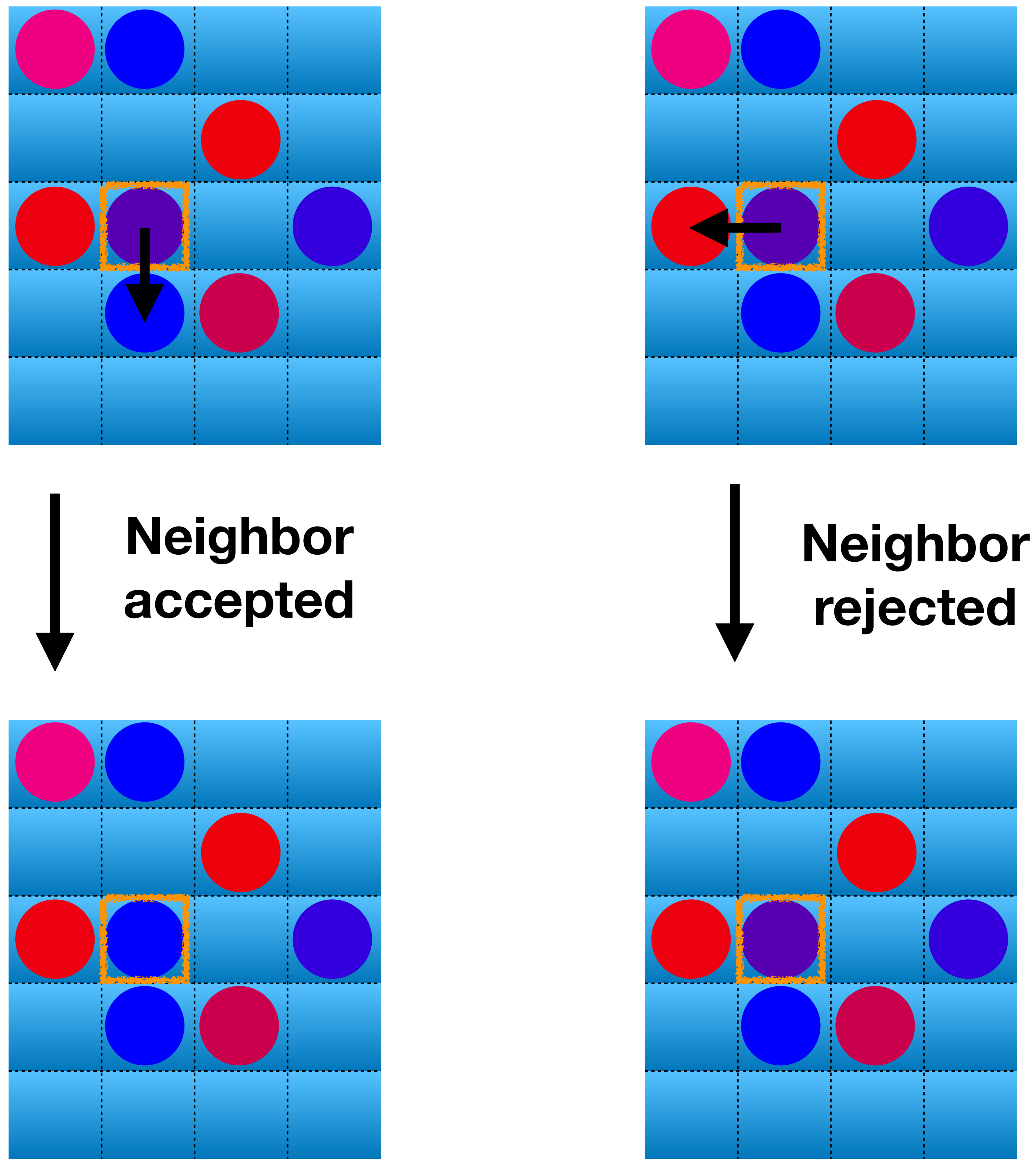
Axelrod model

- Agents have "traits": e.g., favourite color and number ["red", 2]

- Agents adopt traits from other agents they interact with, but are more likely to interact with similar agents

- Agent inspects a random neighbor and checks if it is similar enough:

    - Agent selects a random trait from the neighbour and adapts it to itself



http://ccl.northwestern.edu/netlogo/models/community/Dissemination%20of%20Culture

Axelrod R. The Dissemination of Culture: A Model with Local Convergence and Global Polarization. *Journal of Conflict Resolution*. 1997;41(2):203-226.

Axelrod model

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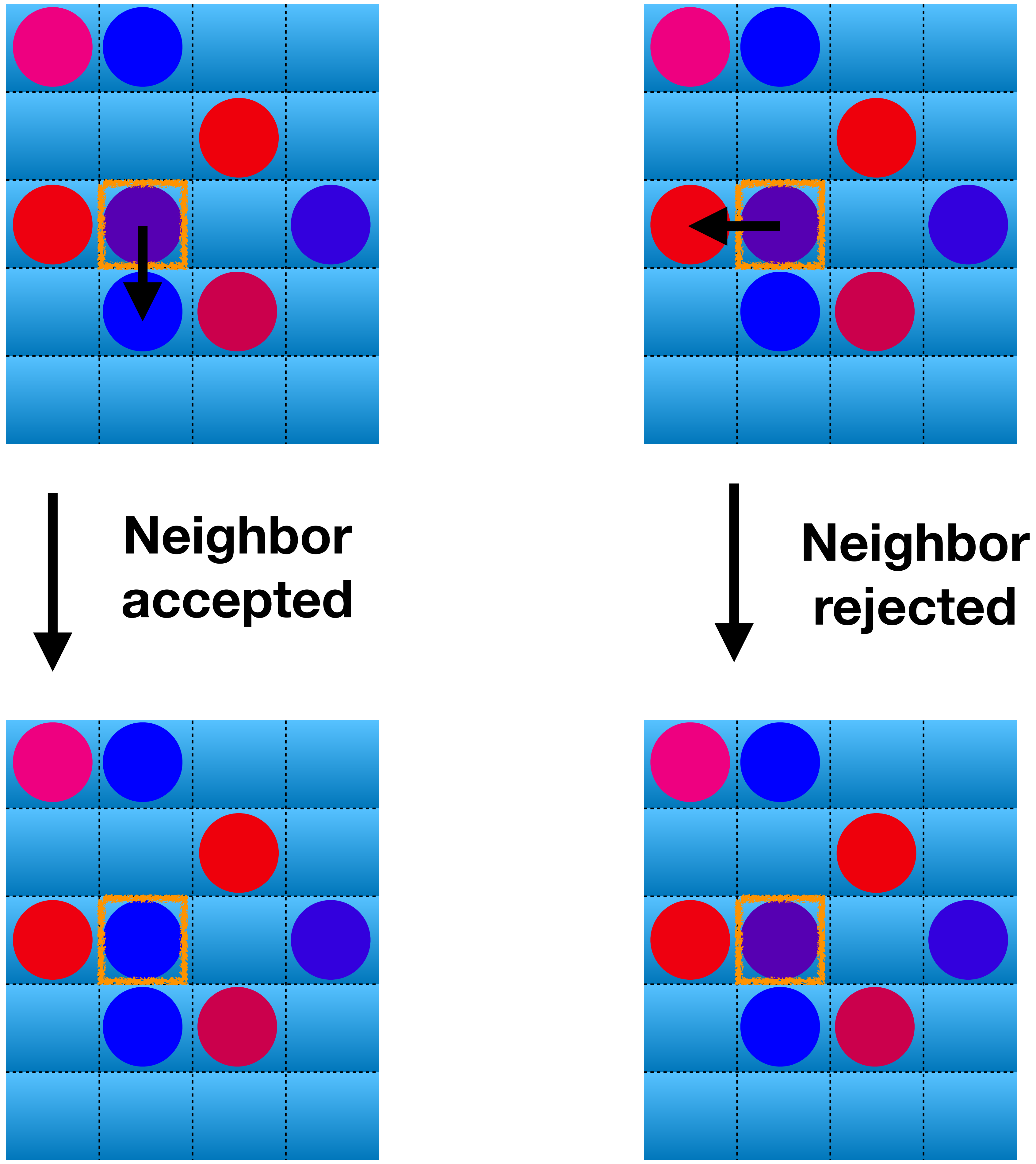
- Agents adopt traits from other agents they interact with, but are more likely to interact with similar agents
- Agent inspects a random neighbor and checks if it is similar enough:
  - Agent selects a random trait from the neighbour and adapts it to itself
- Result: **polarisation**



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Axelrod's model

Microscopic mechanism:
Homophily + *influence*
Macroscopic phenomenon:
Polarization = distinct groups with internally coherent opinions

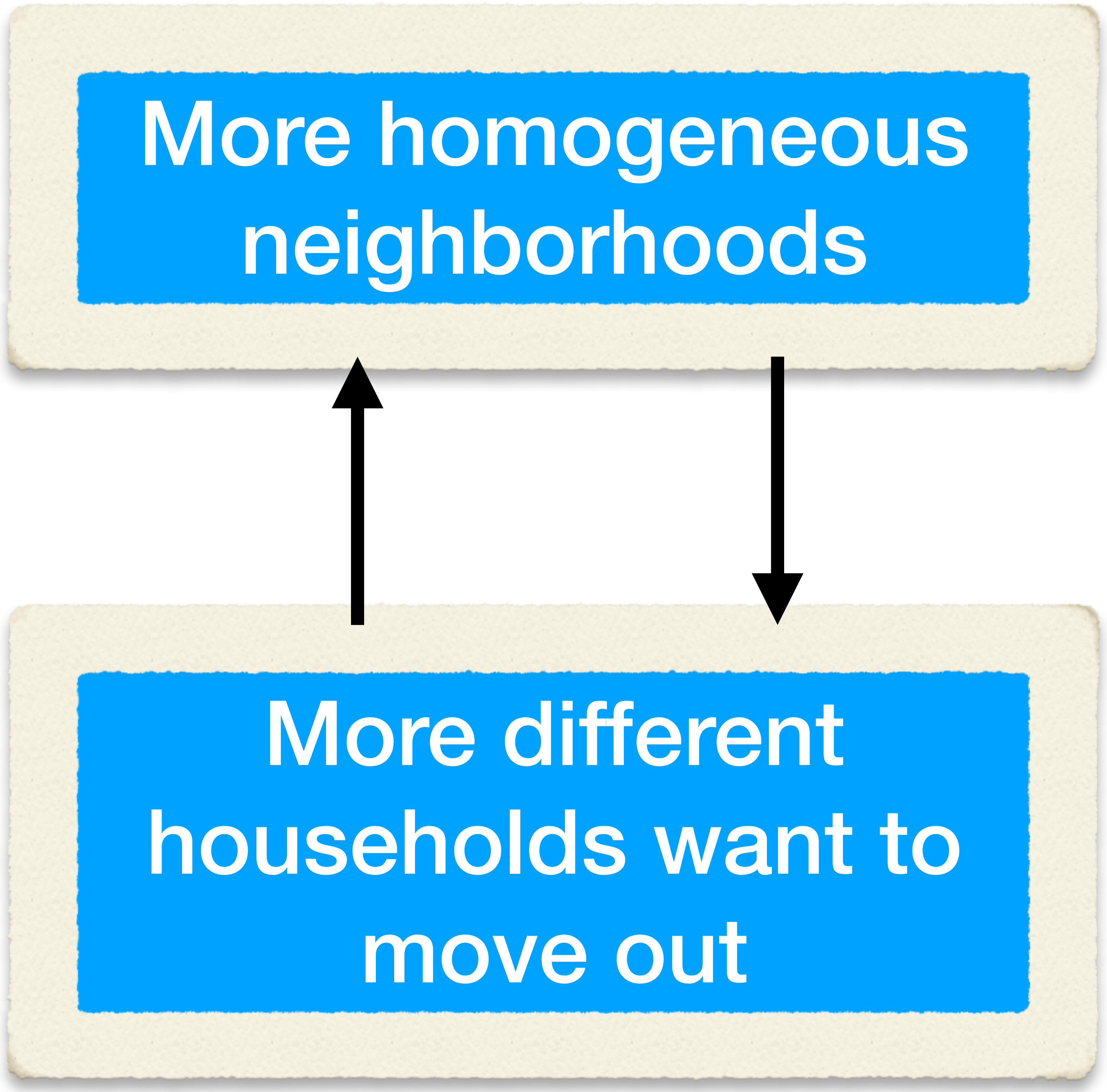
Many other models and variations exists

Bonus exercise:

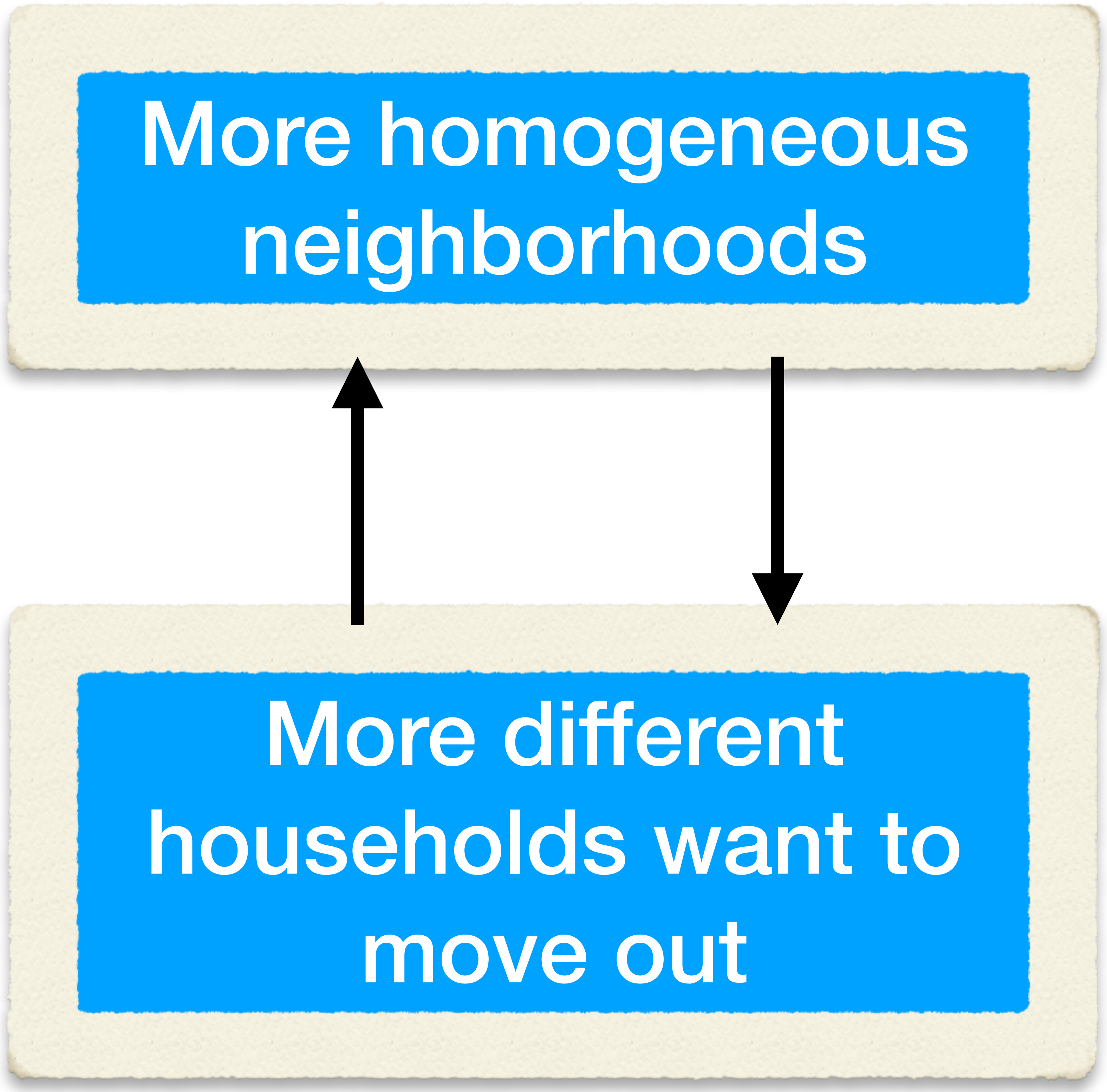
DeGroot model + Attraction-repulsion model

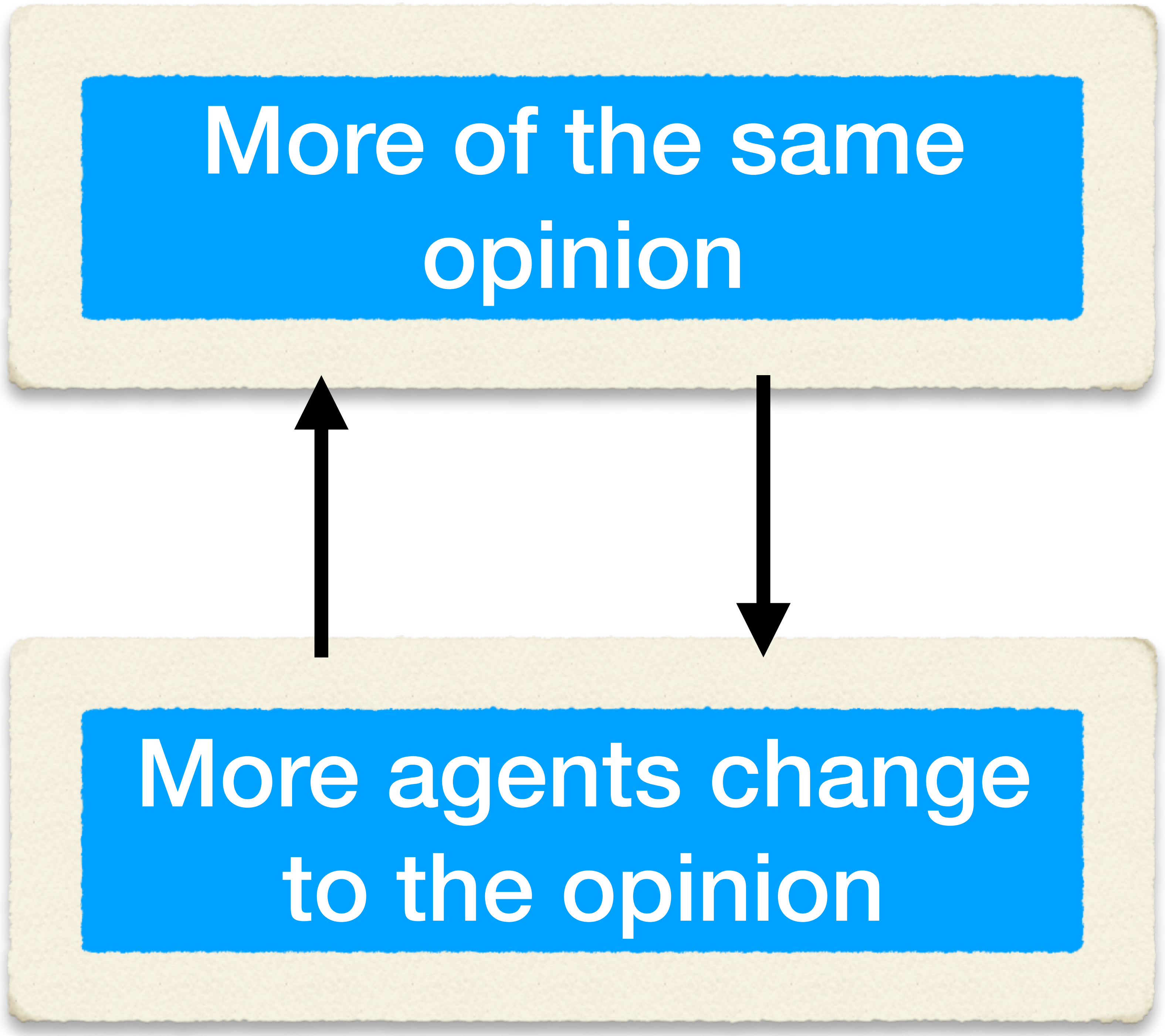
When does individual behaviour lead to emergent phenomena?

Feedback loops → emergent phenomena



Feedback loops → emergent phenomena





We see transitions between

disorder and order

We see transitions between disorder and order

Are these somehow analogous to transitions in physics?

A model for opinion dynamics

- Agent wants to change its opinion, but is influenced by its neighbors
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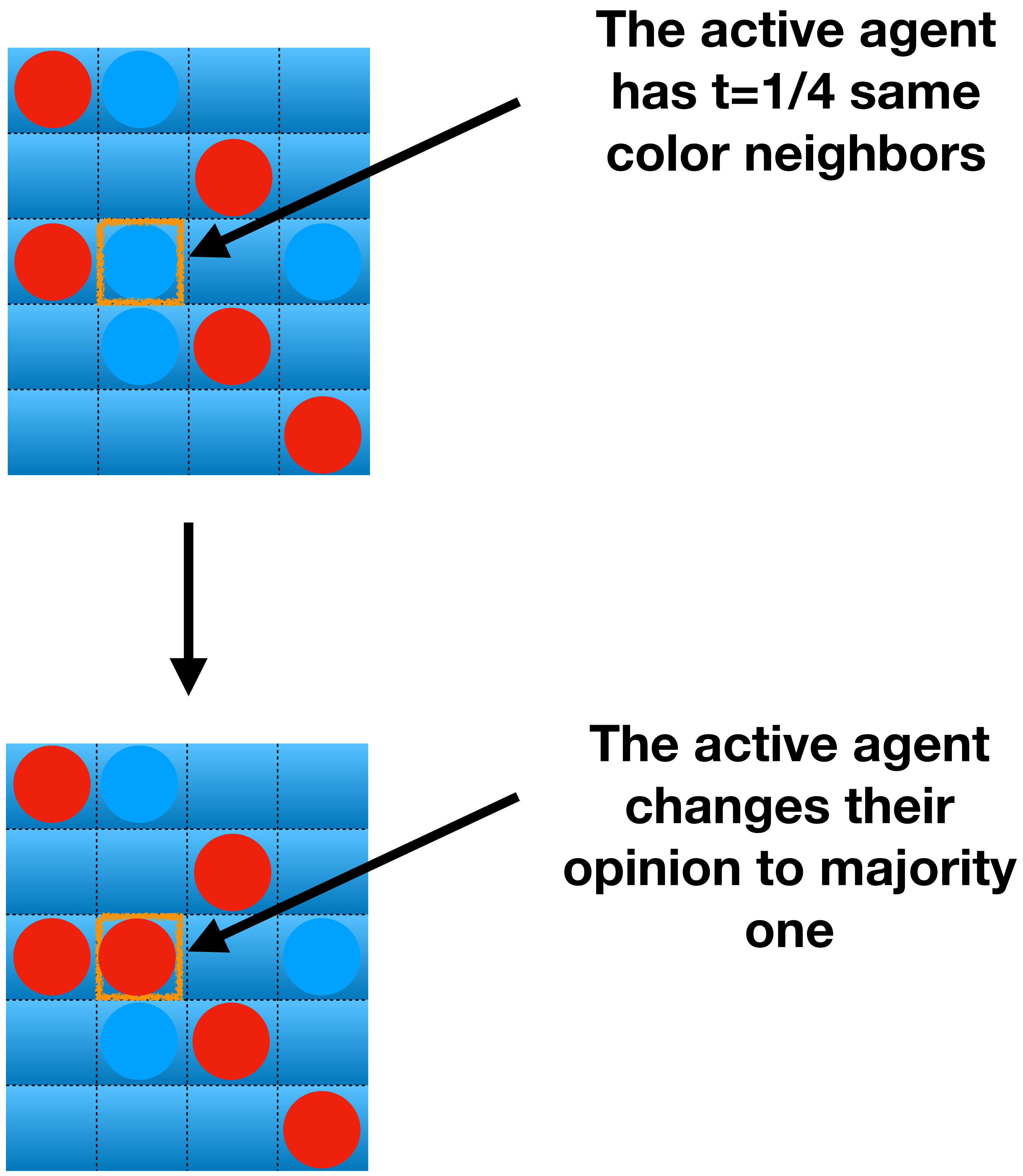
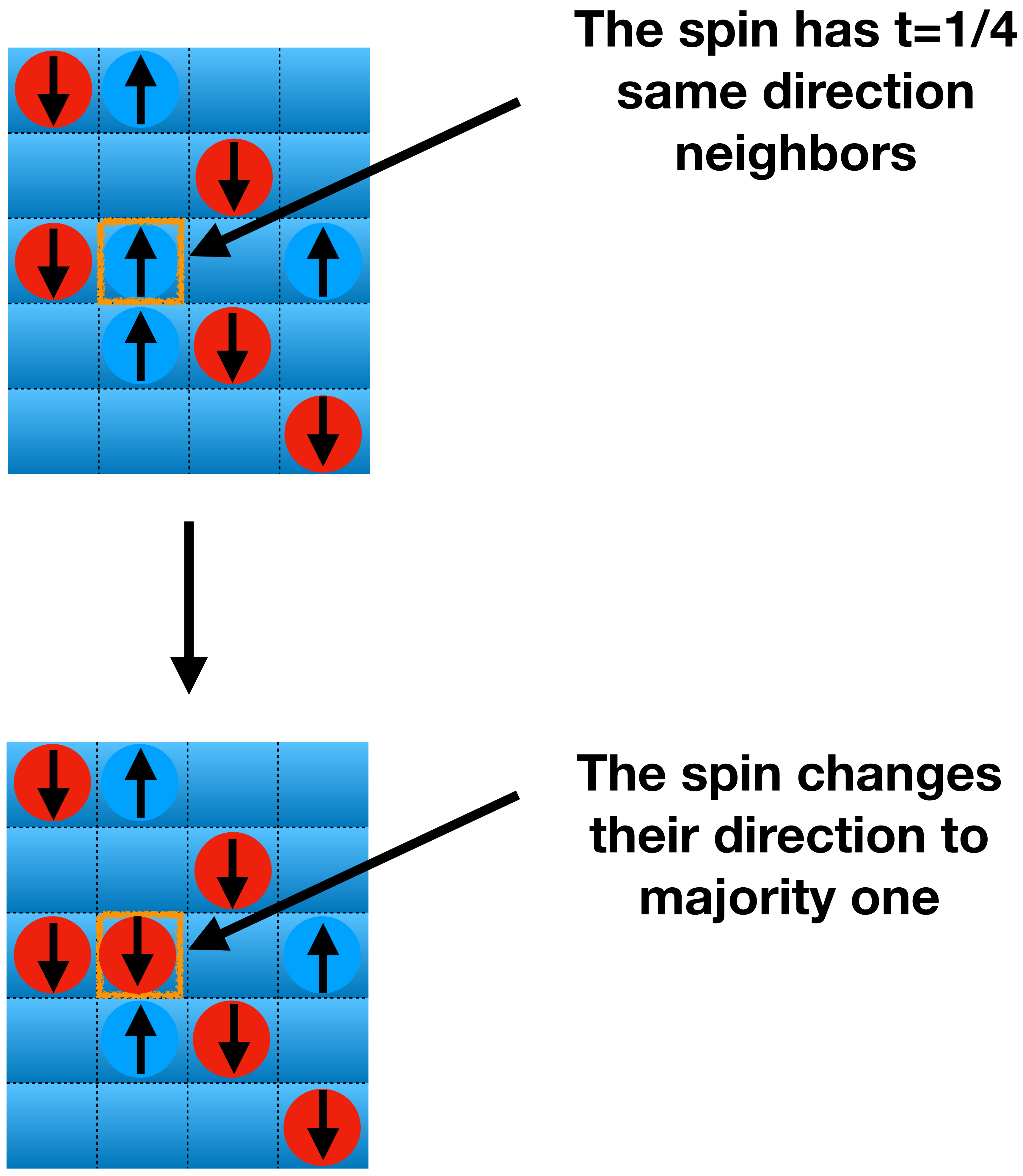


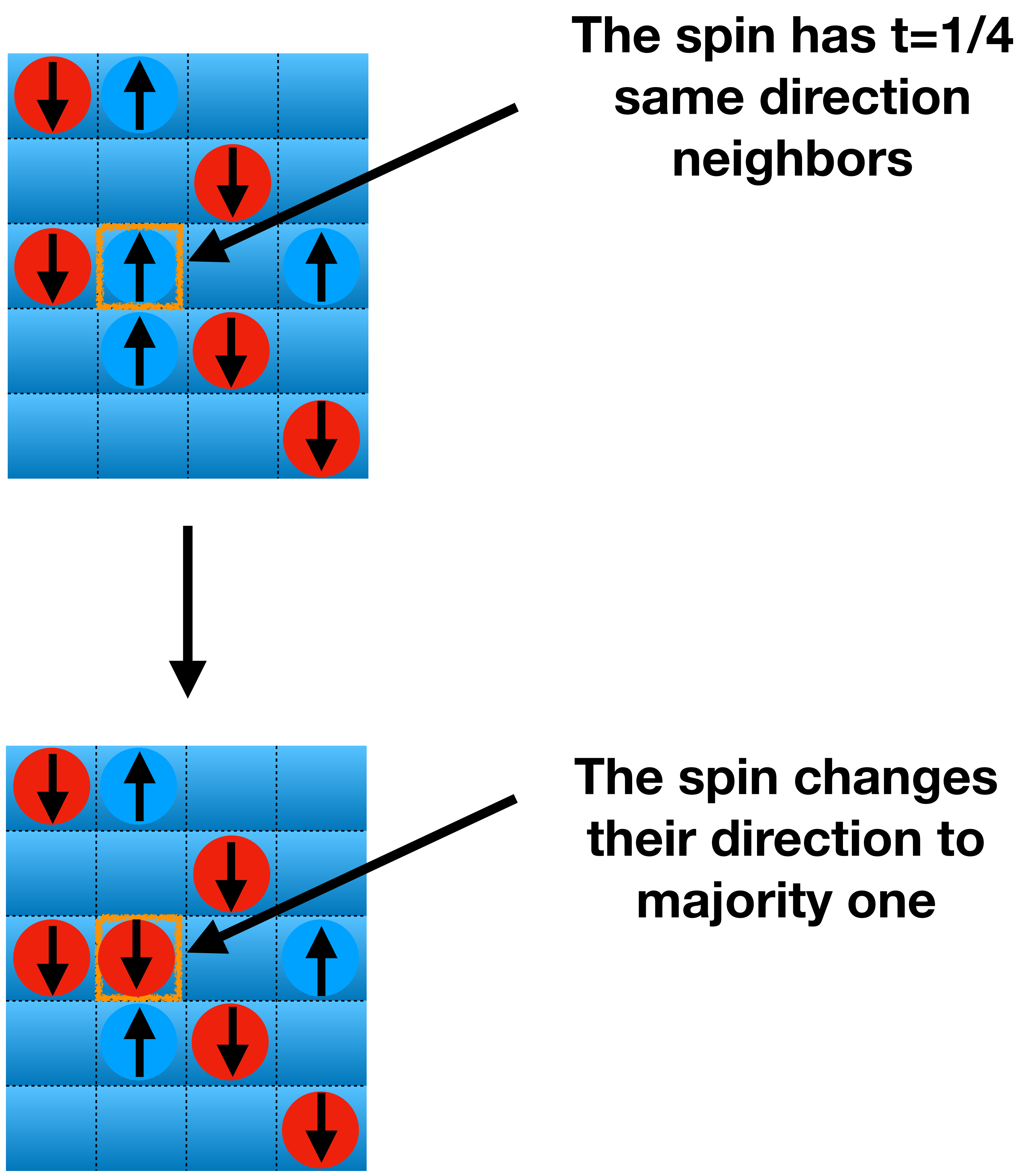
A model for spins (Ising model)

- Magnetic *spins* change their direction randomly due to heat, prefer the direction of spins in the neighborhood
- Spin inspects its neighbourhood:
  - s = number of same spins
  - d = number of different spins
- **If s-d ≤ 0**: the spin changes direction
- **If s-d > 0**: the spin changes its direction with probability $e^{-(s-d)/T}=p^{(s-d)}$, where $p=e^{-1/T}$, and T is temperature



A model for spins (Ising model)

- The Ising model describes magnetisation of materials
  - Also other phenomena like liquid-gas transitions
- Phase transition: metals suddenly become permanent dipole magnet when temperature is lower than a critical value



A model for spins (Ising model)

Studied in physics for around 100 years

ON ISING'S MODEL OF FERROMAGNETISM

BY MR R. PEIERLS

[Communicated by M. BORN]

[*Received* 16 May, *read* 26 October 1936]

Ising* discussed the following model of a ferromagnetic body: Assume N elementary magnets of moment μ to be arranged in a regular lattice; each of them is supposed to have only two possible orientations, which we call posi… negative. Assume further that there is an interaction energy U for ea… neighbouring magnets of opposite direction. Further, there is an exte… netic field of magnitude H such as to produce an additional energy of $-\mu$… for each magnet with positive (negative) direction.

Ising solved the statistical problem only in the one-dimensional… showed that his model does not behave like a ferromagnetic body. For th… of this discussion a ferromagnetic body may be defined as having the… prope… negati… statist…

tends…

In… ferrom… is of a more complicated nature than was assumed by Ising; it depend… on the arrangement of the elementary magnets, but also on the speed w… they exchange their places.

The Ising model is therefore now only of mathematical interest. Si… ever, the problem of Ising's model in more than one dimension has led… deal of controversy and in particular since the opinion has often been… that the solution of the three-dimensional problem could be reduced… the linear model and would lead to similar results, it may be worth wh… its solution.

* Ising, *Zeits. für Physik*, 31 (1925), 253.
† W. Heisenberg, *Zeits. für Physik*, 49 (1928), 619; for an account of th… Heisenberg and the extensions by Bloch and others, see F. Bloch, *Handbuch der*… VI, 2 (Leipzig, 1934), 375.

Beitrag zur Theorie des Ferro- und Paramagnetismus.

…uszug
…r Dissertation
…g der Doktorwürde
…turwissenschaftlichen Fakultät
…gischen Universität
…gelegt von

Ernst Ising
aus Bochum.

HAMBURG 1924

JOURNAL OF MATHEMATICAL PHYSICS VOLUME 4, NUMBER 2 FEBRUARY 1963

Time-Dependent Statistics of the Ising Model*

ROY J. GLAUBER
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts

…of the Ising model are assumed to interact with an external agency (e.g., a heat… them to change their states randomly with time. Coupling between the spins …he assumption that the transition probabilities for any one spin depend on …oring spins. This dependence is determined, in part, by the detailed balancing …e equilibrium state of the model. The Markoff process which describes the …ed in detail for the case of a closed N-member chain. The expectation values …and of the products of pairs of spins, each of the pair evaluated at a different …ly. The influence of a uniform, time-varying magnetic field upon the model …equency-dependent magnetic susceptibility is found in the weak-field limit. …ation theorems are derived which relate the susceptibility to the Fourier …ependent correlation function of the magnetization at equilibrium.

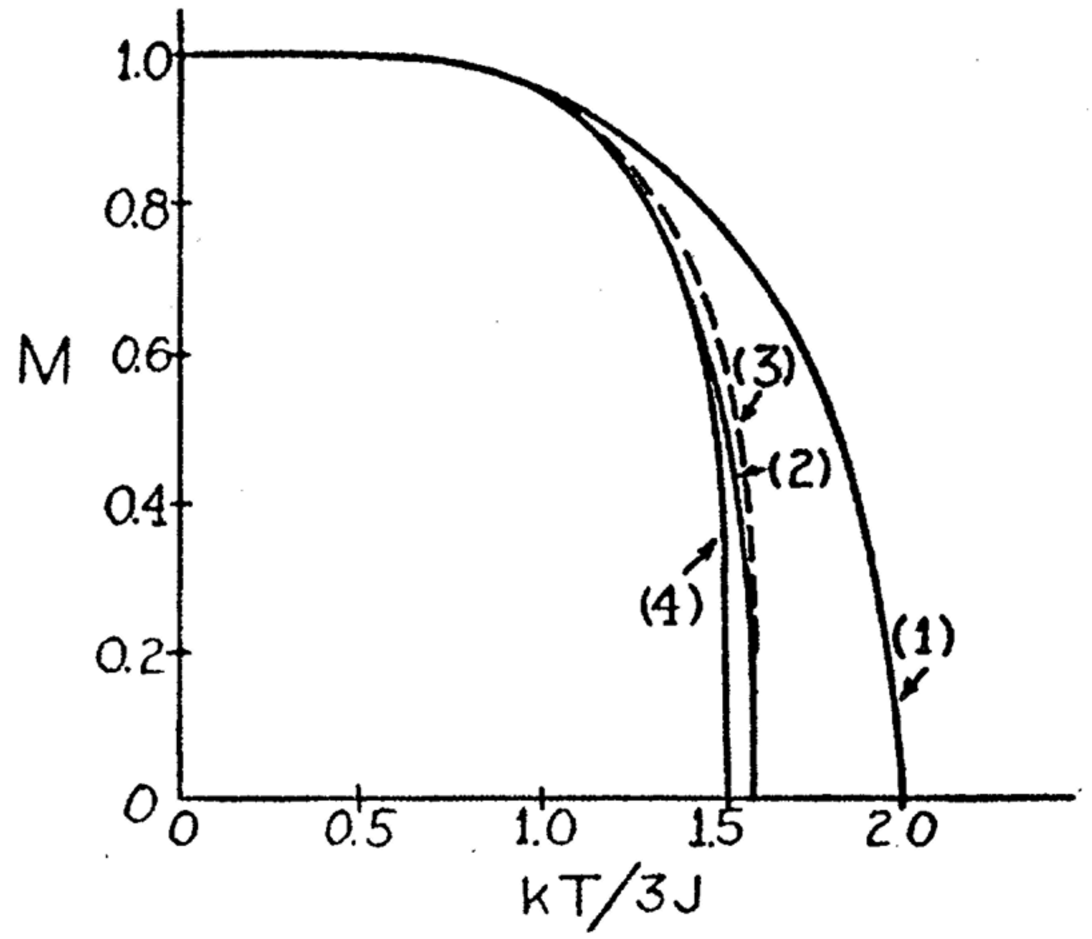


FIG. 25. Approximate spontaneous magnetization curves for the cubic lattice corresponding to the curves of Fig. 24.

A model for spins (Ising model)

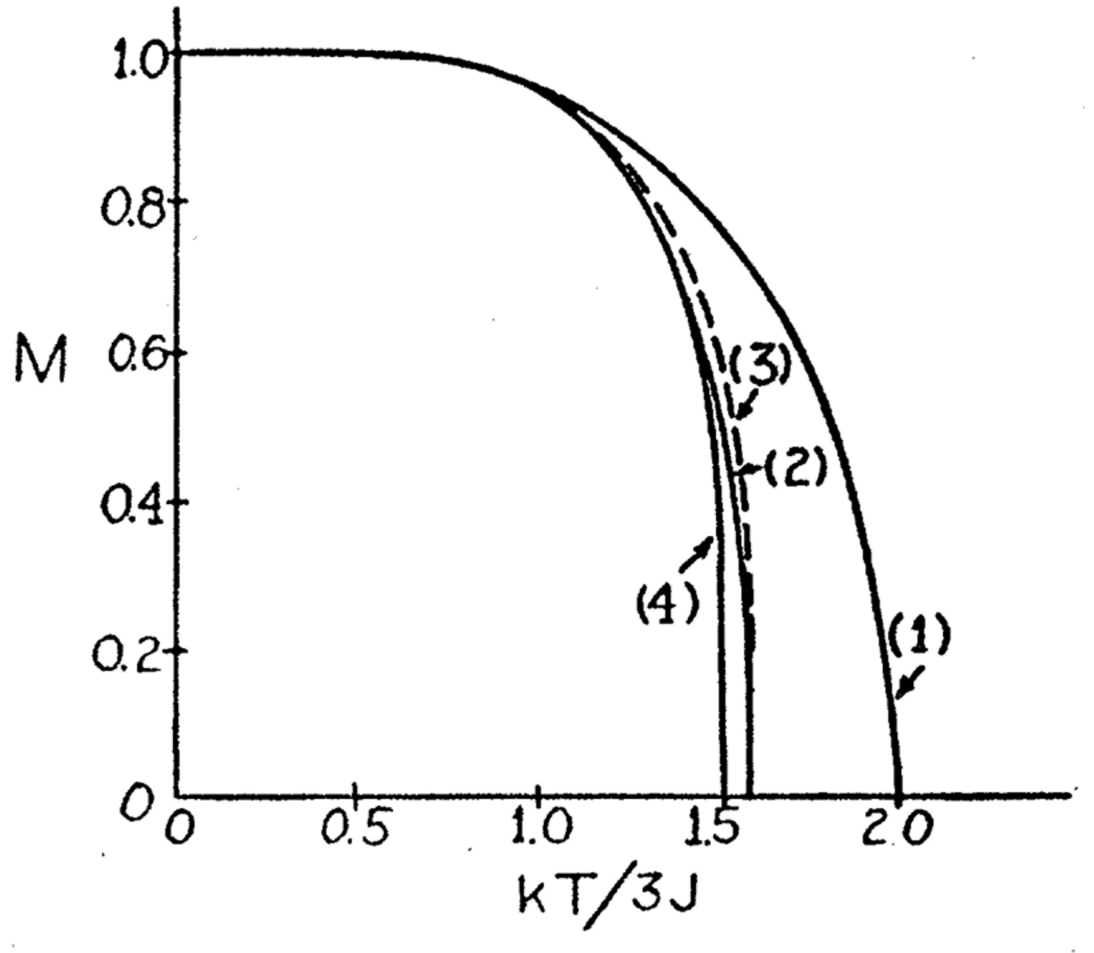
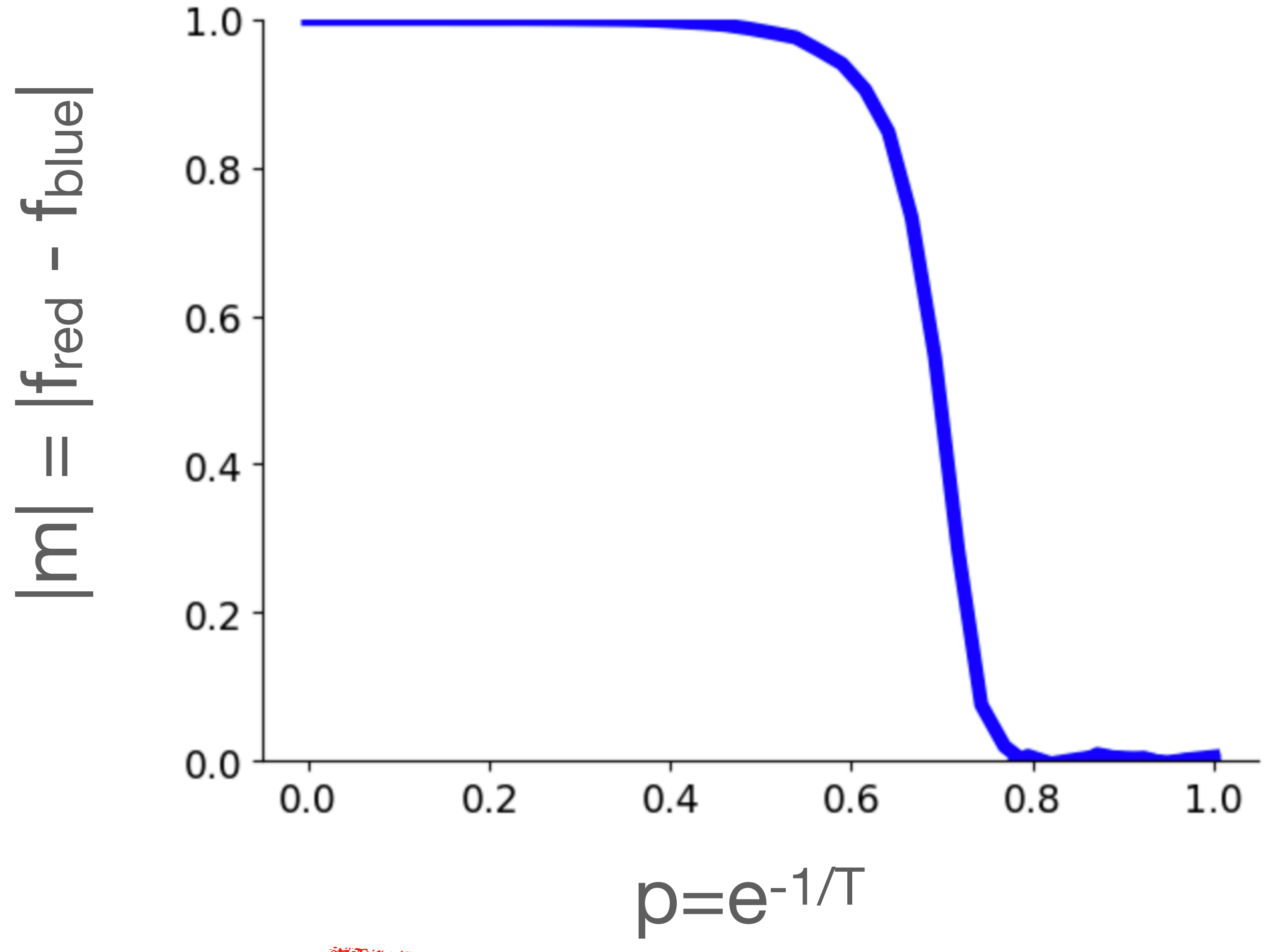


FIG. 25. Approximate spontaneous magnetization curves for the cubic lattice corresponding to the curves of Fig. 24.



Spontaneous magnetisation when temperature decreases

=

Transition to single opinion when probability of convincing to fail (p) decreases

A model for spins (Ising model)

Sawada, S., Nomura, S., Fujii, S. I., & Yoshida, I. (1958). Ferroelectricity in NaN O 2. *Physical Review Letters*, *1*(9), 320.

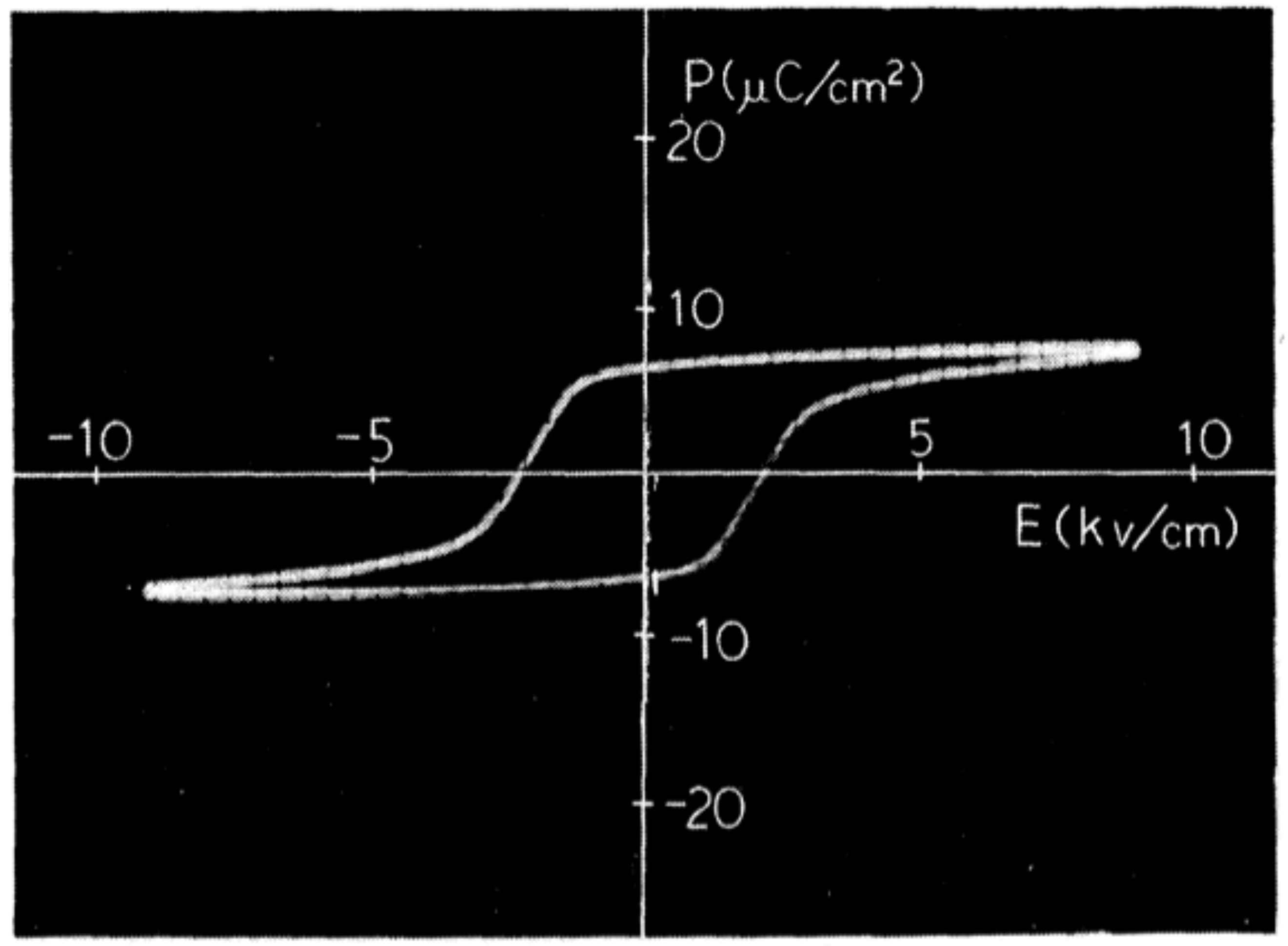
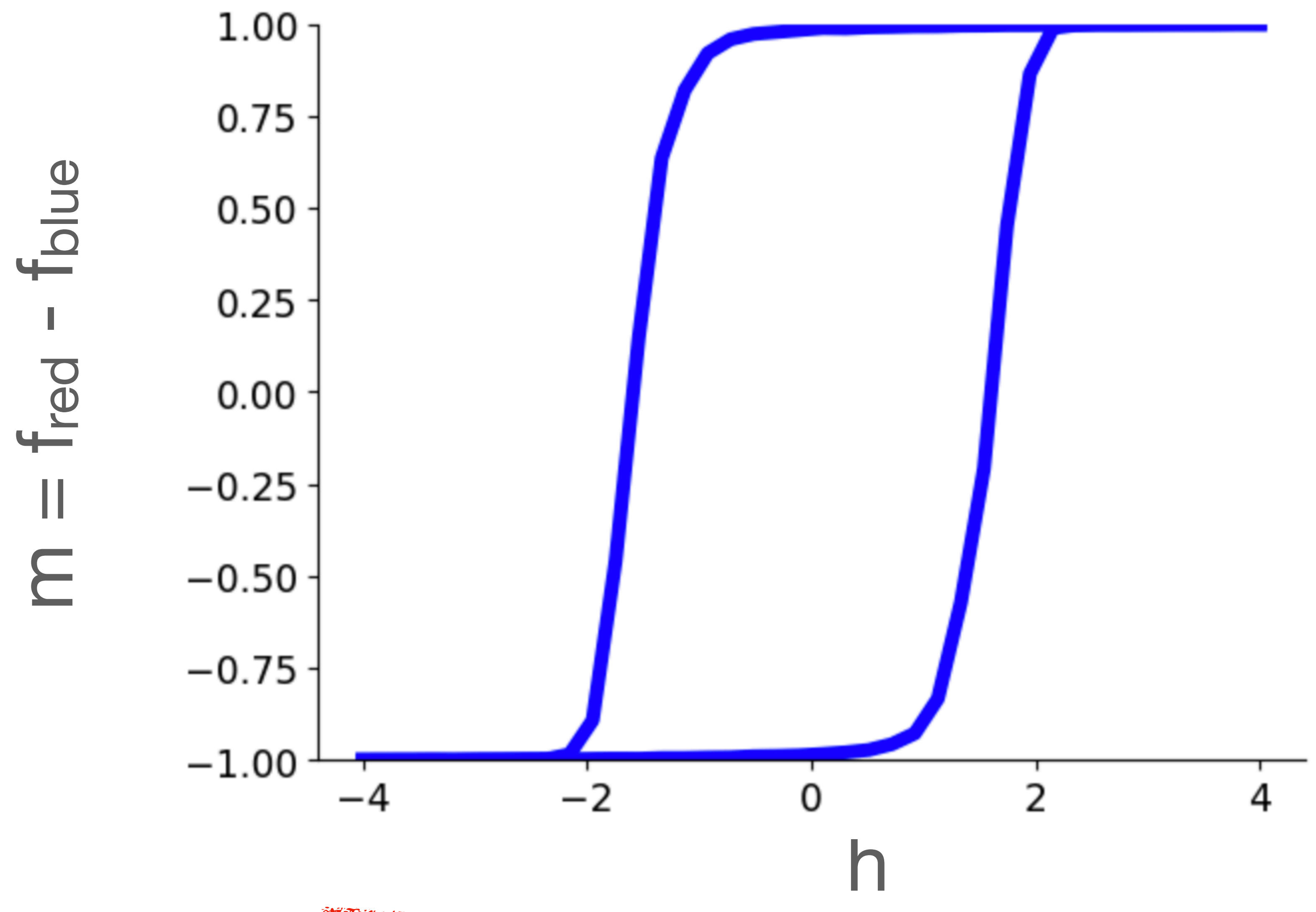


FIG. 2. Hysteresis loop (50 cps) in the direction of b axis at 143°C.



Hysteresis in magnetisation of materials

=

Memory effects in the opinion model

What can we learn from statistical physics?

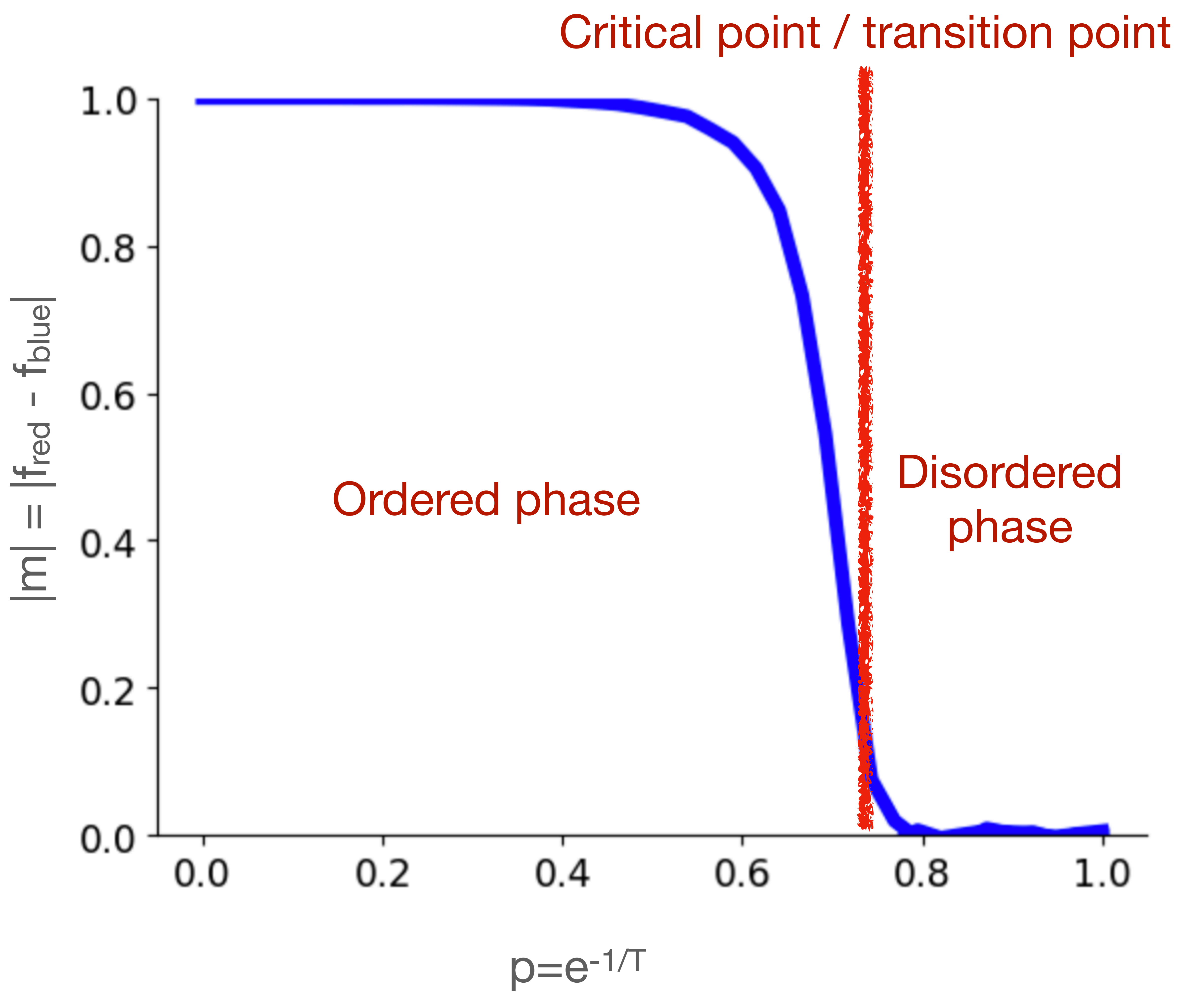
What can we learn from statistical physics?

Concepts, methods, ideas applicable to CSS?

Statistical physics: concepts

- Phase transitions, phase diagrams
- Finite size effects: larger systems → more sharp transitions
- Continuous and discontinuous phase transitions
- Criticality, finding critical points
- Universality

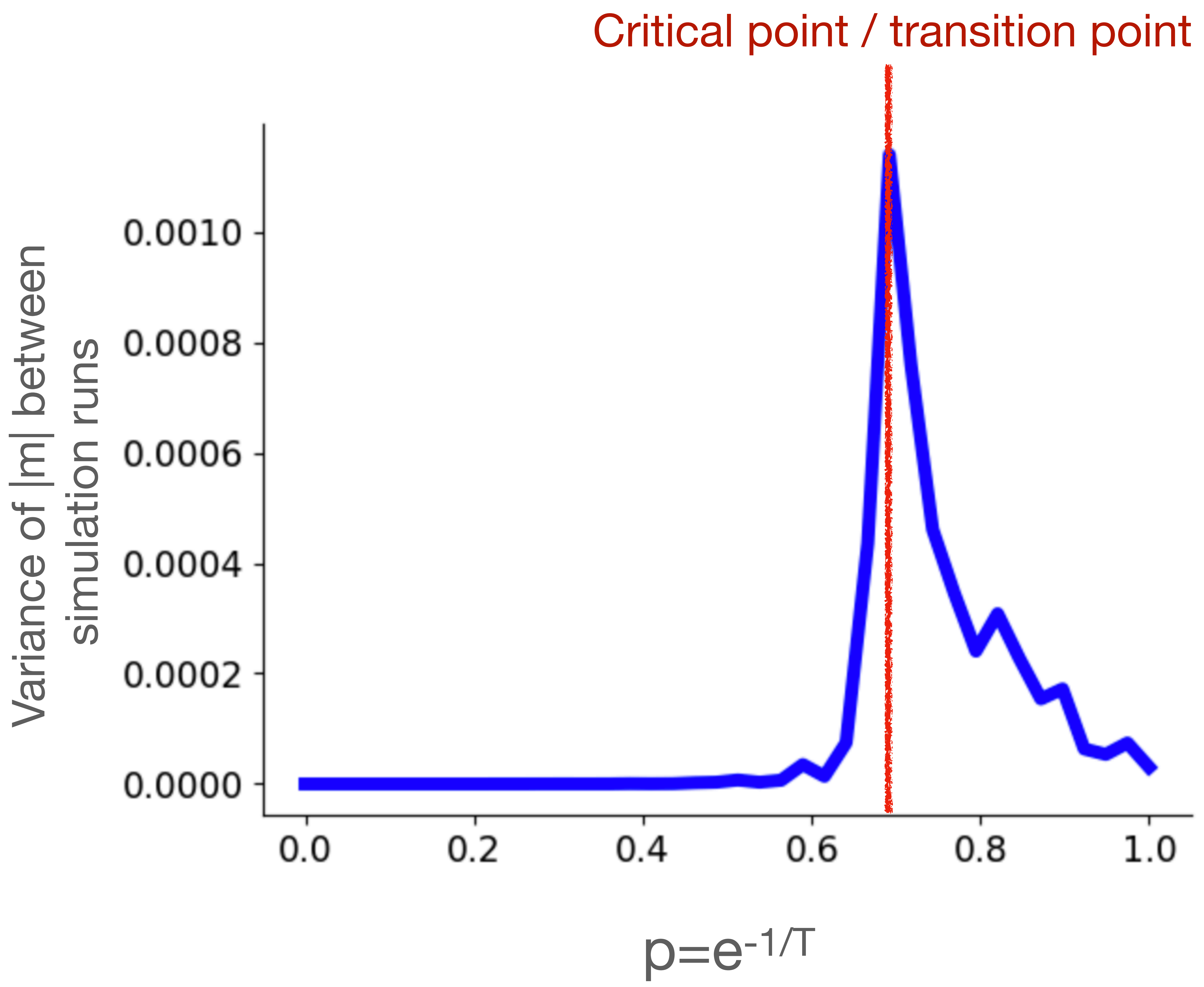
Statistics physics: phase transitions



- Y-axis: order parameter
- X-axis: control parameter
- Disorder to order → phase transition
- Phases, e.g: gas → liquid → solid
- *Critical phenomena* at the transition point

Statistical physics: criticality

- What happens exactly at the transition point?
- Many measures are distributed as power-laws at the critical point, exponentially outside
- Transition point can be detected where the fluctuations are highest



Statistical physics: (dis)continuous phase transitions

Continuous phase transition

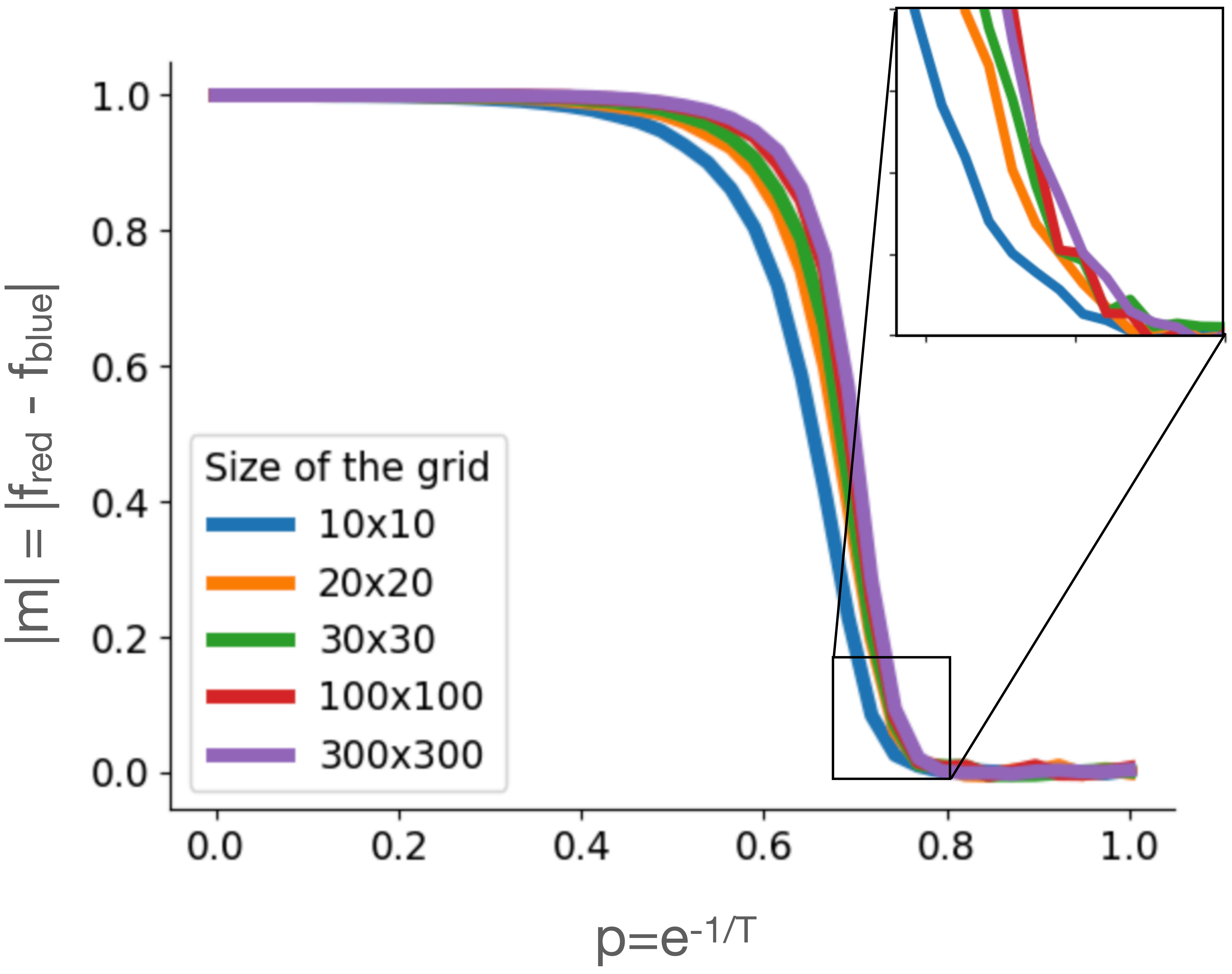
- = “2nd order phase transitions”
- Change between order and disorder continuous
- “Speed” of change at transition point can be different
- Examples so far: Schelling model, temperature Ising model (= p in our opinion model)
- Example next lecture: disease spreading

Discontinuous phase transition

- = “1st order phase transitions”
- A “jump” between order and disorder
- Examples so far: magnetic field in Ising model (= external influence in our opinion model)
- Example next lecture: complex contagion

Statistical physics: finite size effects

- Mathematical computations are often for infinitely large systems
- E.g., larger systems → more sharp transitions
- Finite size scaling: explore transition behaviour for varying size of systems, and extrapolate to infinity

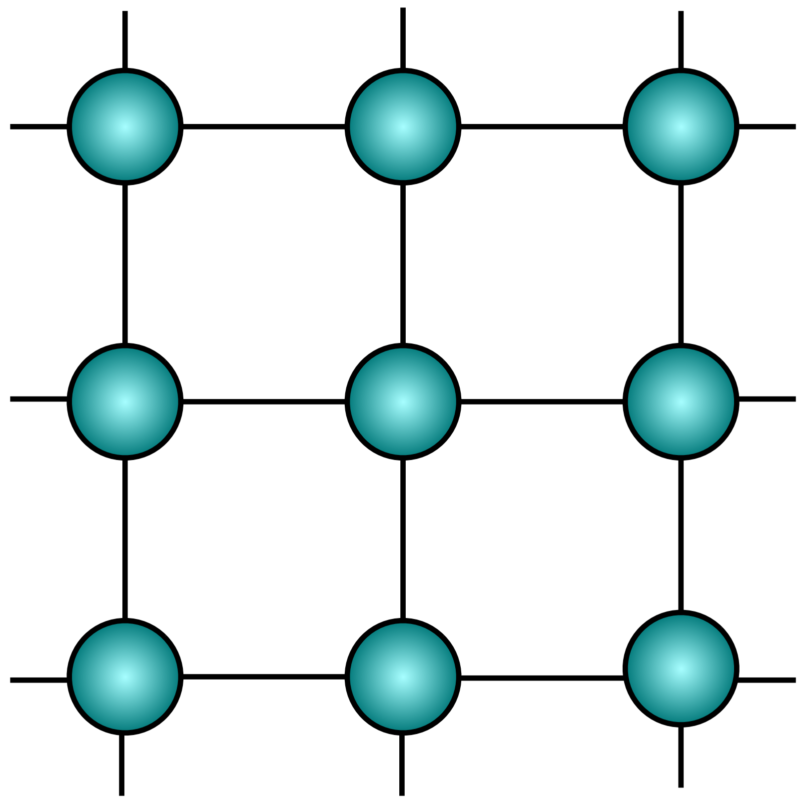


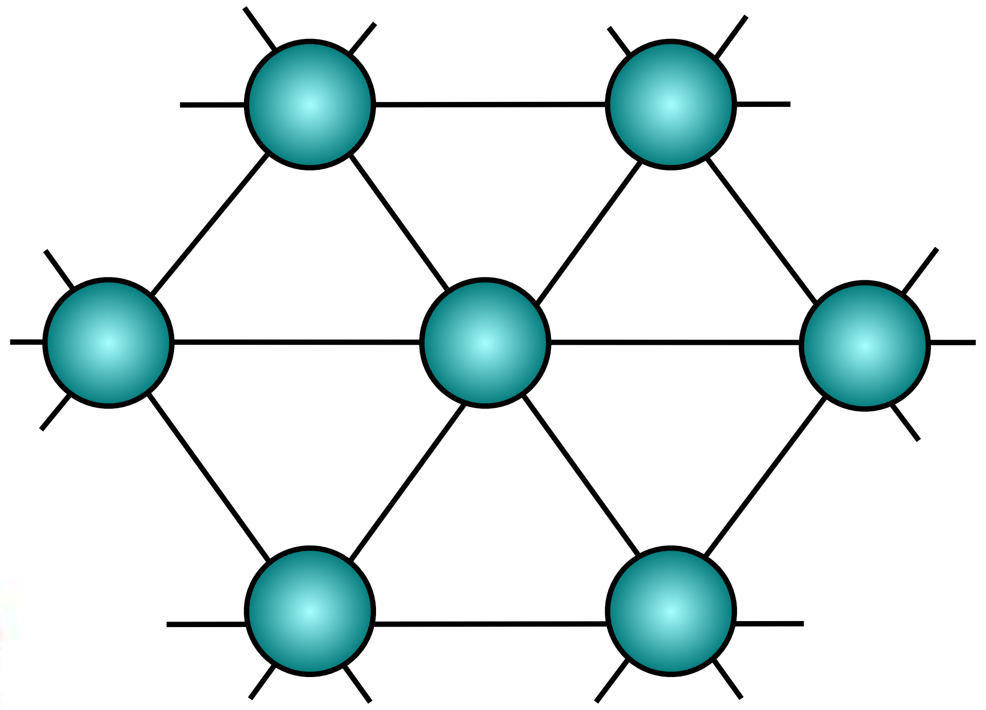
Statistical physics: universality

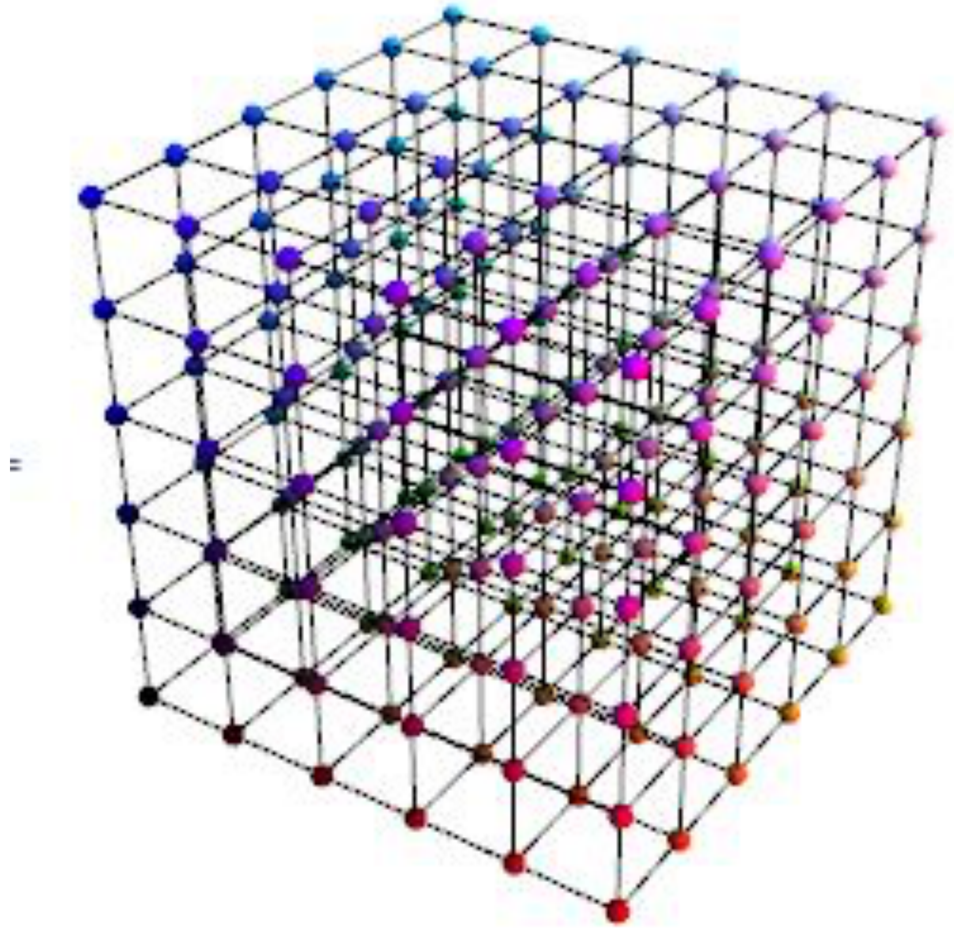
- What if the whole model behavior changes when I change some small detail in the model?

- For example, what if we change the grid?

- **Universality** = details don't matter for the overall behavior







Further reading

Statistical physics of social dynamics

Claudio Castellano[*]

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Santo Fortunato[†]

Complex Networks Lagrange Laboratory, ISI Foundation, Viale S. Severo 65, 10133, Torino, I-ITALY

Vittorio Loreto[‡]

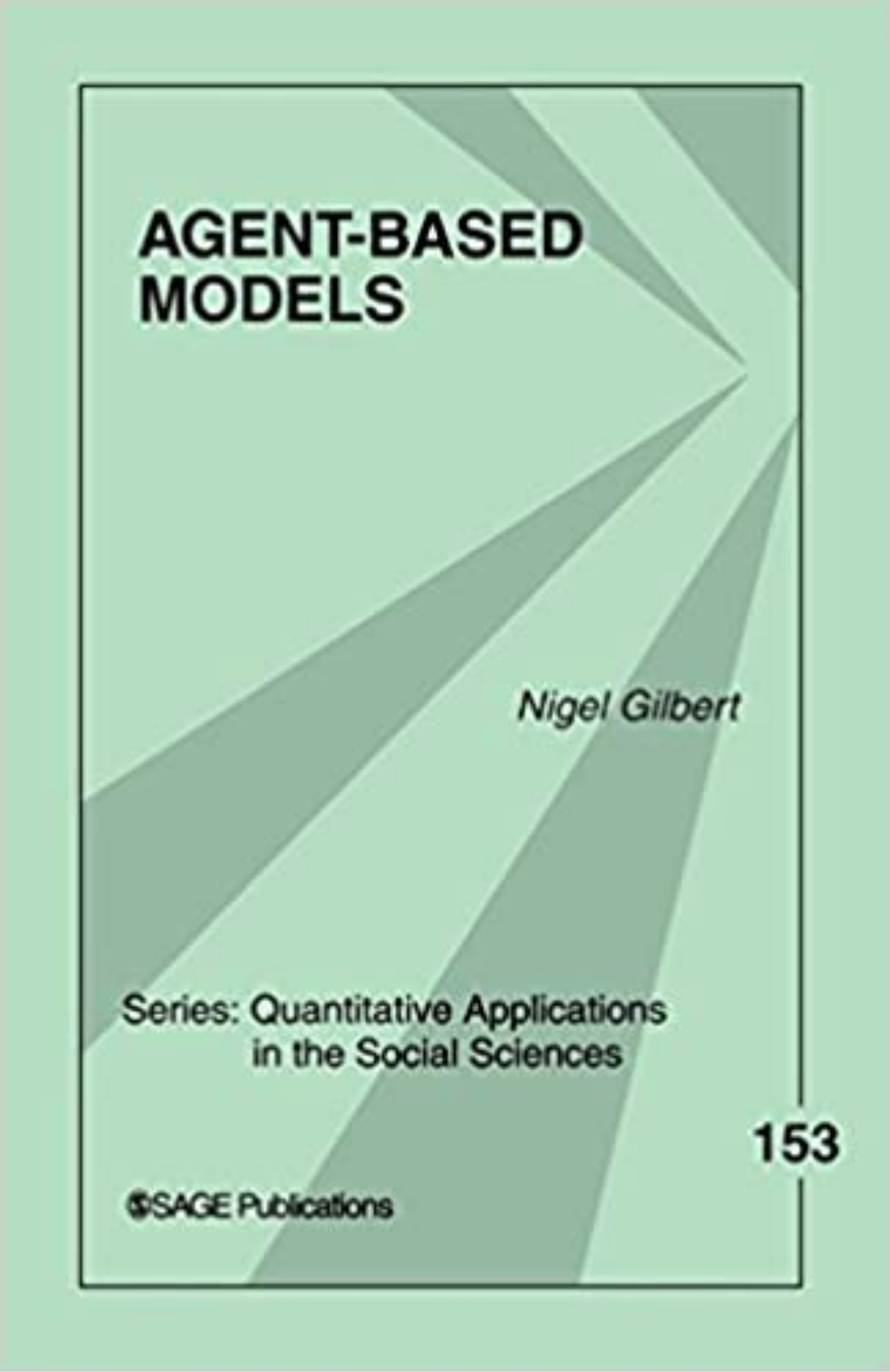
Dipartimento di Fisica, "Sapienza" Università di Roma and SMC, INFM-CNR, Piazzale A. Moro 2, 00185 Roma I-ITALY and Complex Networks Lagrange Laboratory, ISI Foundation, Viale S. Severo 65, 10133, Torino, I-ITALY

Statistical physics has proven to be a very fruitful framework to describe phenomena outside the realm of traditional physics. The last years have witnessed the attempt by physicists to study collective phenomena emerging from the interactions of individuals as elementary units in social structures. Here we review the state of the art by focusing on a wide list of topics ranging from opinion, cultural and language dynamics to crowd behavior, hierarchy formation, human dynamics, social spreading. We highlight the connections between these problems and other, more traditional, topics of statistical physics. We also emphasize the comparison of model results with empirical data from social systems.

Contents

↑Visualisations for this types of models:
http://ccl.northwestern.edu/netlogo/models/Flocking
https://www.youtube.com/watch?v=lOpsnF7uNww

Further reading



frontiers in Physics

REVIEW
published: 17 September 2015
doi: 10.3389/fphy.2015.00078

CrossMark

Mechanistic models in computational social science

Petter Holme[1] and Fredrik Liljeros[2]*

[1] Department of Energy Science, Sungkyunkwan University, Suwon, South Korea, [2] Department of Sociology, Stockholm University, Stockholm, Sweden

Quantitative social science is not only about regression analysis or, in general, data inference. Computer simulations of social mechanisms have an over 60 years long history. They have been used for many different purposes—to test scenarios, to test the consistency of descriptive theories (proof-of-concept models), to explore emergent phenomena, for forecasting, etc… In this essay, we sketch these historical developments, the role of mechanistic models in the social sciences and the influences from the natural and formal sciences. We argue that mechanistic computational models form a natural common ground for social and natural sciences, and look forward to possible future information flow across the social-natural divide.

arXiv:0710.3256v2 [physics.soc-ph] 11 May 2009

Statistical physics of social dynamics

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Statistical physics has proven to be a very fruitful framework to describe phenomena outside the realm of traditional physics. The last years have witnessed the attempt by physicists to study collective phenomena emerging from the interactions of individuals as elementary units in social structures. Here we review the state of the art by focusing on a wide list of topics ranging from opinion, cultural and language dynamics to crowd behavior, hierarchy formation, human dynamics, social spreading. We highlight the connections between these problems and other, more traditional, topics of statistical physics. We also emphasize the comparison of model results with empirical data from social systems.

Contents

Summary

- There are a large number of ABMs and variations of the same models
- Many interesting models exhibit emergent collective behaviour. For example, sudden transitions in overall outcomes based on model parameter
- Ideas from statistical physics can be useful to understand social ABMs:
  - Phase transitions, phase diagrams, critical points
  - Universality, finite size scaling, order of phase transition, hysteresis, …

Questions?